Wkm

nT D, H

JOHN WAIHEE
Governor
MURRAY E. TOWILL
Director
BARBARA KIM STANTON
Deputy Director
RICK EGGED
Deputy Director
TAKESHI YOSHIHARA
Deputy Director

STATE OF HAWAII 1959

DEPARTMENT OF BUSINESS, ECONOMIC DEVELOPMENT & TOURISM

Central Pacific Plaza, 220 South King Street, 11th Floor, Honolulu, Hawaii
Mailing Address: P.O. Box 2359, Honolulu, Hawaii 96804 Telephone: (808) 586-2406 Fax: (808) 586-2377

November 15, 1991

MEMORANDUM

TO: Honorable William W. Paty, Chairman
Department of Land & Natural Resources

Honorable John C. Lewin, M.D., Director
Department of Health

FROM: Murray E. Towill

SUBECT: Geothermal Injection Strategy

Attached is the response of our consultant, GeothermEx, to our request for information on injection particularly as it pertains to Puna Geothermal Venture's plans to inject non-condensible gases, including hydrogen sulfide, along with the other spent geothermal fluids.

This report raises a possibility that the injected gases from KS-3 and KS-4 and perhaps KS-1A can "breakthrough" at the production wells causing, as it did at the Coso Hot Springs field, a decline in power generation and the need for a costly surface hydrogen sulfide abatement system.

We understand that GeothermEx plans to conduct further studies and possibly model the predictive behavior of the injection wells for another client. We will share this information when and if it becomes available.

Should you wish to explain this matter further, we will be happy to arrange a briefing for you by the author of this report.

Murray

MET/GOL:jms:255

Attachment

OCT 23 1991

GeothermEx, Inc.
SUITE 201
5221 CENTRAL AVENUE
RICHMOND, CALIFORNIA 94804-582

(510) 527-9876
CABLE ADDRESS GEOTHERMEX
TELEX 709152 STEAM UD
FAX (510) 527-8164

MEMORANDUM

To: Mr. Gerald Lesperance
Department of Business, Economic Development and Tourism
State of Hawaii (DBEDT)
130 Merchant Street, Suite 1060
Honolulu, HI 96813
Fax: (808) 586-2536

Date: October 23, 1991

From: Subir K. Sanyal
Vice President

Page: 1 of 6

Subject: Geothermal Development in the Kilauea East Rift Zone--Status of Reserves Assessment and Injection Strategy

This memo addresses some basic concerns regarding the status of reserves assessment and the development of an injection strategy for waste water and gases from any power plant to be developed within the Kilauea East Rift Zone (KERZ).

It is generally agreed that a considerable amount of exploitable geothermal reserves exist in the KERZ and possibly in the other rift zones of the Big Island. For example, the Puna Geothermal Venture (PGV) has been able to convince sophisticated investors and major financial institutions that at least a 30 MW (gross) power plant could be supported for 30 years from the reserves within a 500-acre portion of their leasehold. In fact, the Scientific Observation Holes (SOH) program of the State of Hawaii has confirmed the existence of a much larger geothermal system within the KERZ than had been proven before by commercial developers.

Figure 1 shows the temperature distribution at the -4,000 foot datum (below sea level) within the PGV's leasehold before the SOH wells were drilled. In figure 1, from a report written in 1990, the temperature contours on the western flank of the rift are dashed indicating the extrapolated, and therefore unverified, nature of the contours, because no wells then existed on the western side of the rift; for this reason, in 1990 the only proven reserves were considered to exist on the eastern side of the rift and over a few hundred acres of the leasehold in the vicinity of the HGP and the Kapoho State wells. Figure 2, drawn in 1991, shows the temperature distribution within the KERZ, at the -4,000 foot level, after the SOH wells had been drilled. Comparing figures 1 and 2 one can conclude the following:

GeothermEx, Inc.
SUITE 201
5221 CENTRAL AVENUE
RICHMOND, CALIFORNIA 94804-5829

(510) 527-9876
CABLE ADDRESS GEOTHERMEX
TELEX 709152 STEAM UD
FAX (510) 527-8164

- Well SOH 1 confirmed the prior temperature extrapolations to the western side of the rift, thereby nearly doubling the proven thermal anomaly in the vicinity of the PGV project area.

- Well SOH 2 extended the high temperature anomaly, in the northeast direction along the rift zone, several miles beyond the PGV project area.

- Well SOH-1 also indicated the presence of a reservoir boundary on the western flank of the rift, symmetrical to the reservoir boundary indicated by well Lanipuna 6 on the eastern flank.

Besides confirming the existence of a large thermal anomaly, these SOH wells also encountered fractures, thereby proving the existence of exploitable reserves. These wells have confirmed and substantially expanded the proven and probable reserves within KERZ. Thus, the State funds in support of the SOH program have played a major role in establishing the extent of commercial geothermal resource prospects within the KERZ, as well as helping define the boundary of the reservoir, which needs to be known for planning geothermal fluid injection areas.

The best injection strategy for the commercial development of the KERZ is yet to be decided upon. For example, an optimum injection plan for the PGV project has not yet been clearly established. As regards the PGV project, the need for injection (of 100% of the produced mass) is primarily for environmental reasons: the disposal of the waste water and gases from the power plant. The production wells would not rely on injection pressure support.

The original plan of PGV had called for injecting the waste water and gases in a well (or wells) <u>outside</u> the southeastern boundary of the reservoir in the vicinity of well Lanipuna 6; this is a "dry" hole, and therefore, assumed not to be in communication with the reservoir. Lanipuna 6 was known to have encountered a relatively shallow (below 2,000 ft depth) zone of apparently high flow-capacity, which could be used for the disposal of waste water and gases through a well or wells to be drilled into this zone by PGV. The assumption underlying this plan was that the reservoir pressure could be maintained at an acceptable level without any injection into the reservoir; however, this assumption has not yet been validated by numerical modeling of the reservoir behavior. GeothermEx is scheduled to conduct such modeling on behalf of Credit Suisse in a few months.

GeothermEx, Inc.
SUITE 201
5221 CENTRAL AVENUE
RICHMOND, CALIFORNIA 94804-5829

(510) 527-9876
CABLE ADDRESS GEOTHERMEX
TELEX 709152 STEAM UD
FAX (510) 527-8164

Assuming that the reservoir would not need injection pressure support, the above-mentioned plan appears reasonable. Normally, injection outside the reservoir over a long period would not be feasible because the injection pressure would continue to rise due to the lack of any reservoir depletion by production. Fortunately, in this case, injection outside the producing reservoir appears feasible because of two reasons:

- The very high flow capacity of the target zone.
- The relatively small volumetric flow rate (about 1,200 gallons per minute) of waste water requiring disposal.

The original plan for injecting outside the reservoir was meant to eliminate the possibility of cooling due to any premature breakthrough of the cooler injected water to production wells. The plan for injecting the gases as well as waste water from the production wells into the subsurface was based on the desire to eliminate the following:

- major cost of abatement of the noxious component (H_2S) from the non-condensible gases, and
- emission of the residual gases (mainly CO_2), after H_2S removal, to the atmosphere.

The total volume of gas emission to the atmosphere from this project would be small compared to many other geothermal projects because the fluid at the KERZ appears to have a relatively small amount of total dissolved gases. However, the cost of H_2S abatement would be a significant burden because, even though the total gas content is small, the H_2S content in the KERZ fluid is high compared to other geothermal projects.

There are two obvious questions as regards the above-mentioned injection plan:

- Would the water flow rate in the injection stream be sufficient to allow injection of the gases?
- Would the gases or the injected water find their way to the ground water system or even to the ground surface?

Injection of gases in a well requires a minimum amount of simultaneous water injection; otherwise the injection pressure would become impractically high. It is expected that the available waste water injection rate would be nearly enough for gas injection. However,

GeothermEx, Inc. SUITE 201
5221 CENTRAL AVENUE
RICHMOND, CALIFORNIA 94804-5829

(510) 527-9876
CABLE ADDRESS GEOTHERMEX
TELEX 709152 STEAM UD
FAX (510) 527-8164

some make-up water from ground-water wells would have to be used to augment the injection stream. Fortunately, PGV appears to have an abundant ground-water supply.

We believe that the danger of gases or injected water appearing on the ground surface or in ground-water aquifers is very small for two reasons:

- The targeted injection zone is much deeper than the local ground-water aquifers.
- The gas concentrations would be diluted by mixing with the subsurface water in the injection zone and partially consumed by reaction with subsurface fluids and rocks.

It is theoretically possible, but largely impractical, to model the possible interaction between the gases and water injected into the target zone and the overlying ground-water aquifers, because of the following reasons:

- No practical numerical modeling approach exists that can simultaneously model the fluid flow, heat transfer and complex interactions between the gases, water and rocks in a non-isothermal ground-water system.
- No information exists on the hydraulic as well as chemical nature of the target injection zone or the exact chemical nature of the injection water and gases.

We have recently learned that PGV is reconsidering its original plan and now intends to inject into wells KS-3 and KS-4 and perhaps KS-1A, located within the production area, instead of in wells outside the reservoir. This plan has two advantages:

- It eliminates any potential leakage of gases or waste water into the ground-water aquifers.
- It would provide some pressure support to production wells.

However, it also has two potential disadvantages:

- Possible cooling of production wells due to the breakthrough of cooler, injected water, and
- possible breakthrough of the injected non-condensible gases at the production wells.

GeothermEx, Inc.
SUITE 201
5221 CENTRAL AVENUE
RICHMOND, CALIFORNIA 94804-582

(510) 527-9876
CABLE ADDRESS GEOTHERMEX
TELEX 709152 STEAM UD
FAX (510) 527-8164

We consider the second disadvantage to be a more serious concern.

The only geothermal field in the U.S. where non-condensible gases from production wells are being injected into the production reservoir is the Coso Hot Springs field in California. At Coso Hot Springs, the injected gases have broken through at several production wells. This has caused the following problems:

- The power generation level has declined due to the increase in the gas content of the steam.
- The capital cost has increased because of the need to install an H_2S abatement system not originally planned for.
- The operations and maintenance costs have increased due to the need for H_2S abatement.
- A gas discharge permit had to be obtained from the local air pollution control district which was not originally planned for.

It is possible that these problems would occur at the KERZ given the new injection plan.

It is theoretically possible to forecast the extent of the cooling and gas-breakthrough problems by reservoir modeling; but given the complexity of the problem, the scanty knowledge about this geothermal system and the relative lack of data, such modeling is difficult, if not impossible, at this time. GeothermEx will, however, develop such a model on behalf of Credit Suisse after the PGV's drilling and well-testing activities are completed. Because of our substantial experience in modeling this aspect of the Coso Hot Springs field, we anticipate being able to accomplish this difficult modeling task.

PGV points out that while the production and injection wells at the KERZ are closer to each other than at Coso Hot Springs, the vertical distance between the production and injection zones would be higher. However, this fact cannot be fully assessed until well KS-8 is tested and PGV updates their production/injection strategy.

Finally, it is worthwhile considering the steps that can be taken by the DBEDT to improve the confidence in the geothermal energy reserves underlying the KERZ and to help define an optimum production/injection strategy. We believe that the most practical step that the DBEDT can take at this time is to help finance drilling and testing of exploratory wells, either slim holes or production size wells. We do

GeothermEx, Inc.
SUITE 201
5221 CENTRAL AVENUE
RICHMOND, CALIFORNIA 94804-5829

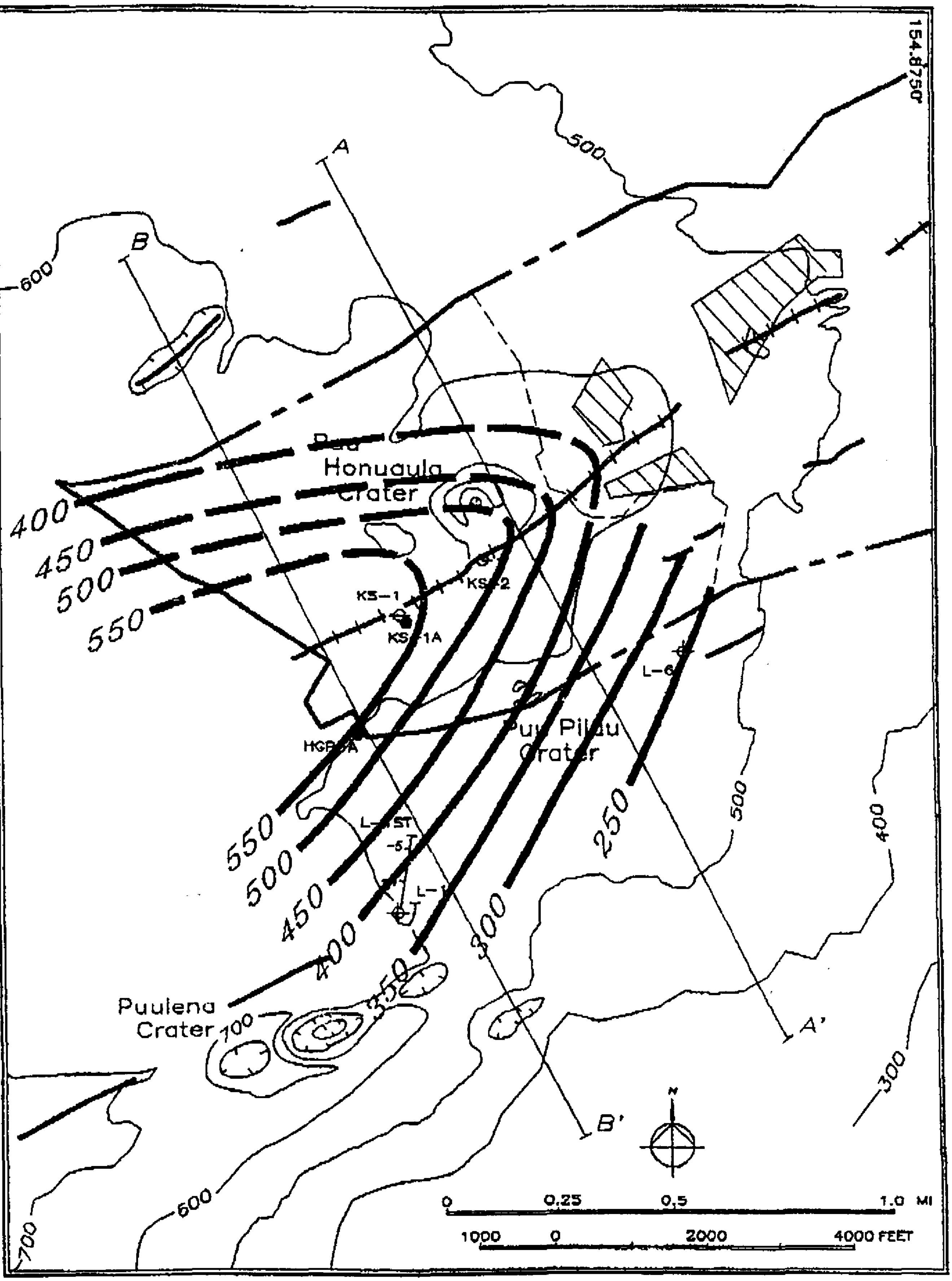
(510) 527-9876
CABLE ADDRESS GEOTHERMEX
TELEX 709152 STEAM UD
FAX (510) 527-8164

not believe that other technical activities, such as surface exploration, laboratory studies or computer modeling, by themselves, would be effective in improving the confidence of investors in the geothermal development prospects in Hawaii.

After 15 years of geothermal exploration and the construction and operation of a demonstration power plant for 7 years, only 30 MW (gross) of power is under development in Hawaii. If the ultimate goal of 500 MW of power on the Big Island is to be realized, a minimum investment of 2 billion dollars would be necessary, not counting the enormous cost of a subsea cable. This amount of investment obviously cannot be funded either by the State or the Federal government. Major financial institutions and most equity investors would be willing to fund a power plant development only after the reserves are confirmed by drilling and testing of wells; exploration activity cannot be debt-financed. Surface exploration, laboratory studies or computer modeling, without a simultaneous program of drilling and well testing, would not have any attraction to potential debt-financiers or even most equity investors, and therefore, would not provide any impetus towards geothermal development in Hawaii. Indeed, because they are not "bankable," such studies would serve only to delay commercial geothermal development in Hawaii. By contrast, an impetus from the DBEDT is all the more necessary now that the drilling, environmental and public relations problems in the PGV and True-Mid Pacific projects have cast a shadow on the future financing prospects for geothermal development in Hawaii.

If you wish, I would be prepared to explain and amplify the above ideas, illustrating them with comparable case histories of several other fields, and answer any related questions in a meeting of the DBEDT and other concerned parties.

Best regards.



LEGEND

400 Temperature, °F	• Production well	Fault and downthrow direction
Lease boundary	Dry hole	Fissure (1955 eruption zone)
Exclusions from lease	Plugged hole	Fracture

Figure 1: Temperature distribution at −4,000 feet, msl

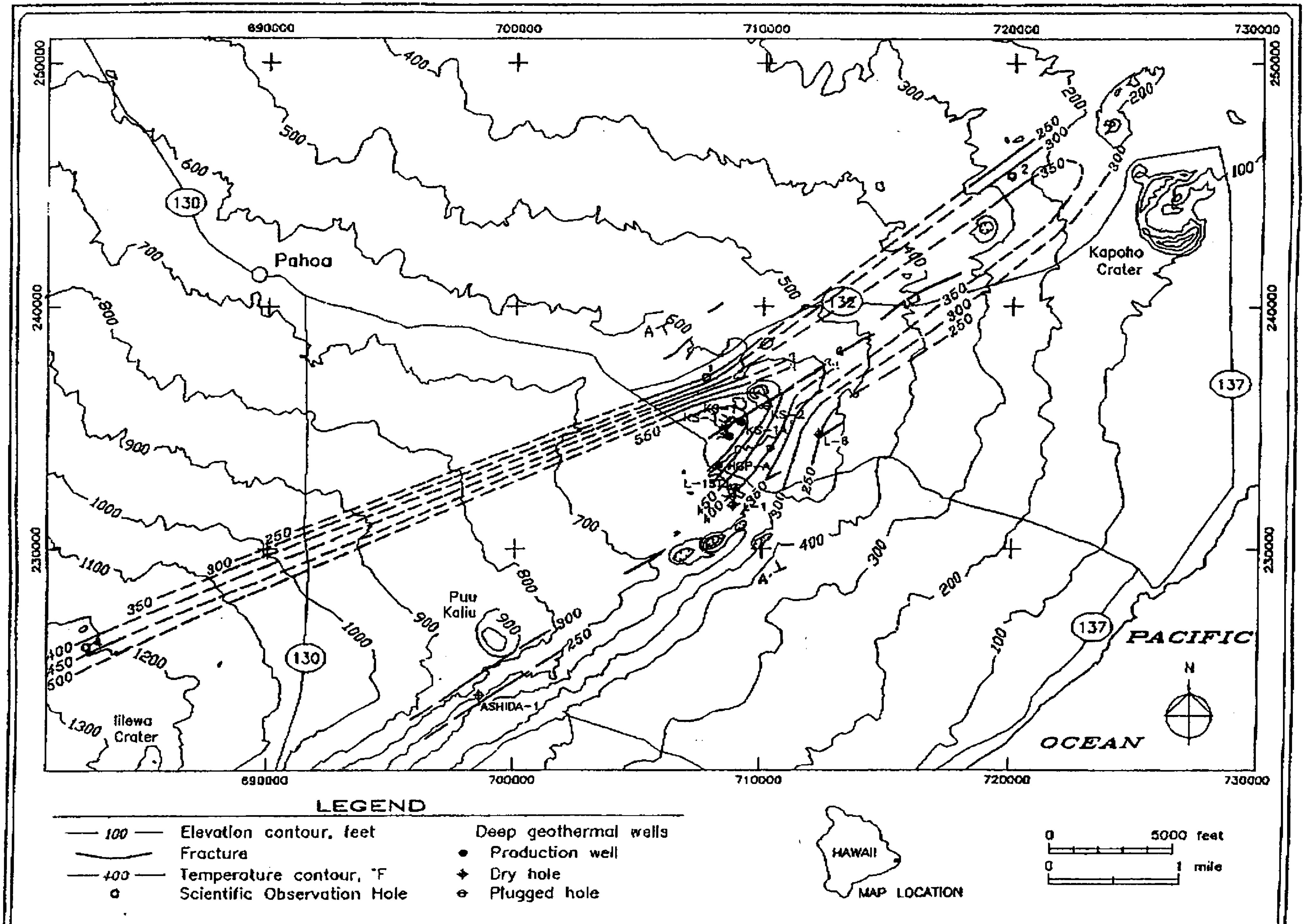


Figure 2: Temperature distribution at −4,000 feet, msl

1991, GeothermEx, Inc.