Research Proposal to the National Science Foundation
Research Applied to National Needs (RANN)
Advanced Energy Research and Technology

by

University of Hawaii
Honolulu, Hawaii 96822

HAWAII GEOTHERMAL PROJECT - PHASE II

REVISION TO PROPOSAL AER7500285-000

Amount Requested: $995,000

Proposed Duration: Twelve Months

Requested Starting Date: January 1, 1975

Principal Investigator:

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Signature	John W. Shupe

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Signature	George P. Woollard	John P. Craven

Co-Principal Investigators and Program Directors:

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Name	Paul C. Yuen	Robert M. Kamins
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Signature	Paul C. Yuen	Robert M. Kamins

Approving Administrative Official:

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Title	Associate Dean for Research
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Signature	

HAWAII GEOTHERMAL PROJECT
PHASE II PROPOSAL REVISION

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HAWAII GEOTHERMAL PROJECT
PHASE II PROPOSAL REVISION

ABSTRACT OF PROPOSAL REVISION

The original proposal for continuing support for the Hawaii Geothermal Project (HGP) through calendar year 1975 was submitted to NSF July 1, 1974. Included in the total budget request of $1,986,000 was $1,206,000 to initiate an exploratory drilling program at three potential geothermal sites on the Big Island of Hawaii. Subsequent negotiations with NSF geothermal personnel drastically reduced the budget ceiling and necessitated this proposal revision.

The revised budget of $995,000 reflects a reduction in the Drilling Program from $1,206,000 to $580,000 and will fund only one deep hole in the Puna Area. The support programs are reduced by 47% from the original proposal, and represent a near-minimum level of support, if the interdisciplinary aspects of the HGP are to be retained.

This proposal revision was prepared as a supplement to the major proposal submitted in July, and is not intended to stand as an independent document. The Overview section--as well as those for Management, Engineering, and Environmental-Socioeconomics--contains only brief narratives explaining the adjustments from the original program plans brought about by imposed budget cuts.

The Geophysical Program was completely redone and makes up the bulk of this revised proposal. It presents a summary of the geological, geochemical, and geophysical tasks completed to date--including additional survey results and interpretation of data completed since the original proposal was submitted. Also included is a description by task of the total Geophysical research program to be undertaken during 1975.

The narrative for the Drilling Program presents the rationale for selecting an appropriate drilling site and planning an optimum drilling program within the stringent budget limitations. This rationale was developed through interpretation of the most recent geological and geophysical data, as well as tentative negotiations with the probable drilling contractor.

HAWAII GEOTHERMAL PROJECT
PHASE II PROPOSAL REVISION

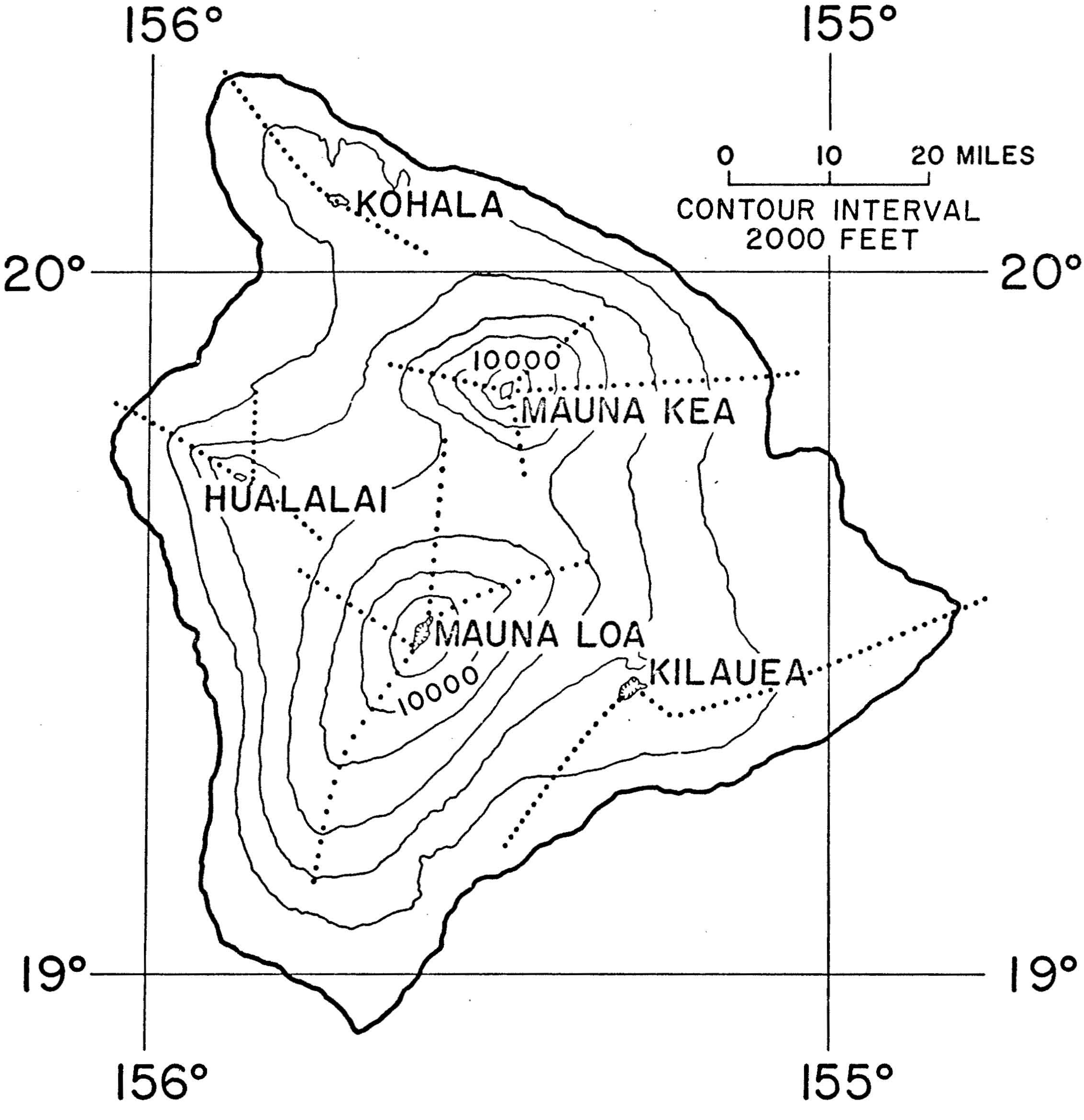
OVERVIEW OF PHASE II REVISIONS

Phase I of the HGP will be completed December 31, 1974. The major emphasis during this 19-month research program has been on geophysical explorations, but complementary activity has proceeded also on engineering, environmental, economic, legal and regulatory studies. Major funding for Phase I has come from the National Science Foundation ($588,000) and from the State and County of Hawaii ($200,000).

Results from Phase I, in conjunction with surveys and studies conducted over many years by a number of organizations, indicate some promise for conventional geothermal anomalies existing on the Big Island. Phase II, an exploratory drilling program, was proposed to investigate these potential geothermal anomalies and to provide actual subsurface data with which to verify the reliability of different geological and geophysical predictions of subsurface conditions in Hawaii.

The Phase II proposal for calendar year 1975, as submitted July 1, 1974, requested $1,986,000--of which $1,206,000 was to be used to initiate an exploratory drilling program at three potential geothermal sites. Referring to Figure I, these sites were to be fairly close to the sea along three rift zones: 1) The Eastern Kilauea Rift in the Puna Area; 2) The Southwest Rift of Kilauea; and 3) The Southwest Rift of Mauna Loa.

Subsequent negotiations with NSF geothermal personnel have lowered the budget ceiling significantly. Table I shows a comparison in financial support by program and by task between the original and revised budgets. Drilling funding has decreased from $1,206,000 to $580,000, while support programs of management, geophysics, engineering, and socioeconomics were reduced



VOLCANOES & RIFT ZONES ON THE ISLAND OF HAWAII

Figure 1

TABLE I - HAWAII GEOTHERMAL PROJECT PHASE II

BUDGET SUMMARIES BY PROGRAM AND TASK
January 1 Through December 31, 1975

MANAGEMENT	INITIAL REQUEST	REVISED PROPOSAL TOTAL BUDGET	RESIDUAL BALANCE AT 12/31/74	NEW NSF FUND REQUEST
1.0 Coordination and Support	$ 39,401	$ 26,339	$ 0	$ 26,339
GEOPHYSICAL PROGRAM				
2.0 Coordination and Support	43,454	44,577	7,479	37,098
2.2 Geoelectric Surveys	58,709	44,393	12,080	32,313
2.3 Modelling, Magn. & Grav. Surveys	33,625	30,784	8,190	22,594
2.4 Temperature Survey	43,124	18,903	8,262	10,641
2.5 Seismic Studies	57,000	36,664	11,200	25,464
2.6 Geochemical Studies	36,718	27,915	10,843	17,072
2.7 Hydrology	35,107	31,860	11,550	20,310
2.8 Physical Properties of Rocks	49,191	39,934	20,450	19,484
Subtotal	356,928	275,030	90,054	184,976
ENGINEERING PROGRAM				
3.0 Coordination and Support	41,774	23,880	1,000	22,880
3.1 Geothermal Reservoir Engineering	122,892	70,288	4,000	66,288
3.6 Optimal Geothermal Plant Design	87,781	65,832	4,000	61,832
Subtotal	252,447	160,000	9,000	151,000
ENVIRONMENTAL-SOCIOECONOMIC PROGRAM				
4.0 Coordination and Support	24,824	23,338	3,549	19,789
4.1 Environmental Aspects	42,313	9,990	4,212	5,778
4.2 Legal and Regulatory Aspects	6,800	800	800	0
4.3 Land-Use and Planning Aspects	11,415	0	0	0
4.4 Economics	46,411	28,644	1,211	27,433
Subtotal	131,763	62,772	9,772	53,000
EXPLORATORY RESEARCH DRILLING PROGRAM				
5.0 Drilling Contract and Support	1,205,974	579,925	0	579,925
TOTAL	$1,986,513	$1,104,066	$108,826	$995,240

TABLE II

HAWAII GEOTHERMAL PROJECT

PROGRAM PLANNING AND EXPENDITURE SCHEDULE

	PHASE I		PHASE II
	May 1973 – May 1974	May 1974 – Jan 1975	Jan 1975 – Jan 1976
1.0 Management	$ 51,865	$ 11,920	$ 26,339
Hawaii Advisory Committee			
National Liaison Board			
2.0 Geophysical Coordination & Support	45,270	47,768	37,098
2.1 Photogeologic Surveys	23,900		
2.2 Geoelectric Surveys	62,626	60,798	32,313
2.3 Theoretical and Numerical Modelling, Computational Geophysics, Magnetic and Gravity Surveys	44,871		22,594
2.4 Temperature Survey		27,638	10,641
2.5 Seismic Studies	79,135	30,687	25,464
2.6 Geochemical Surveys		24,109	17,072
2.7 Hydrology			20,310
2.8 Physical Properties of Rocks			19,484
3.0 Engineering Coordination and Support	14,886	12,463	22,880
3.1 Geothermal Reservoir Engineering	44,924	38,813	66,288
3.6 Optimal Geothermal Plant Design	38,533	27,765	61,832
4.0 Environmental-Socioeconomic Program Support	36,690	14,100	19,789
4.1 Environmental Aspects		11,426	5,778
4.2 Legal and Regulatory Aspects	9,300		
4.3 Land-Use and Planning Aspects			
4.4 Economics		17,561	27,433
5.0 Exploratory Research Drilling Program		10,552	579,925
	$452,000*	$335,600	$995,240

*Includes $100,000 from State of Hawaii and $100,000 from County of Hawaii an average of 47%. The revised budget will fund only one deep hole in the Puna Area, rather than multiple drilling at three potential sites, and has caused across-the-board cuts in all support programs. Table 1 also lists the amount of carry-over funds from Phase I that are still unencumbered. The final column shows the amount of new support requested from NSF in this proposal.

A revised planning and expenditure schedule, reflecting the budget reductions, is shown in Table II. The expenditures for Phase I through December, 1974 are listed by task, as well as projected expenditures through Year I of Phase II. This table provides an overall summary of the total research activity and related funding that has gone into the project to date, along with the projected research program and budget through December, 1975.

In the Sections that follow:

1.0 Management
2.0 Geophysical Program
3.0 Engineering Program
4.0 Environmental-Socioeconomic Program
5.0 Drilling Program,

each Co-P.I. discusses the changes necessitated by the budget cuts and presents a revised research plan for his respective program. For Management, Engineering, and the Environmental-Socioeconomic Programs only brief narratives and revised budgets are included, since the information contained in the original proposal requires only minor adjustments to reflect the changes imposed by the reduced budget.

The description of the Geophysical Program, however, was completely redone and should be considered as a total replacement for that section from the original proposal. Consequently, the Geophysical Program makes up the bulk of this proposal revision. It provides a review of all of the tasks conducted to date--geological, geochemical, and geophysical--including additional survey results and evaluations completed during the four-month interim since the original proposal was submitted. Also revised are descriptions for each task of the research programs to be undertaken during 1975.

The section on the Drilling Program reinforces the rationale developed by Geophysics for locating the one drilling site in the Puna Area, and lists the information to be obtained from this exploratory research drill hole. It also justifies how the limited drilling budget can be most effectively utilized to obtain this information and is based upon negotiations with the probable drilling contractor.

BUDGET SUMMARIES

Immediately following are six budget summaries--the total budget, plus one each for Management and the Geophysical, Engineering, Environmental-Socioeconomic, and Drilling Programs. Budgets for each of the individual tasks are included with the narrative descriptions of the separate programs.

The figures tabulated on these budget worksheets represent the total amount budgeted for a given category for calendar year 1975. Also listed is the projected residual balance, or carry-over funding, from Phase I as of December 31, 1974. The Adjusted Request represents the total amount of new support from NSF.

HAWAII GEOTHERMAL PROJECT
BUDGET SUMMARY

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	John W. Shupe

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. 5 (Co) Principal Investigator(s)		6	6	$ 36,879*
b. 16 Faculty Associates	17	4.5	17	64,372*
Sub-Total				
2. Other Personnel (Non-Faculty)				
a. 2 Research Associates—Postdoctoral	12	9	3	19,245
b. ___ Non-Faculty Professionals				
c. 17 Graduate Students				71,336
d. 14 Pre-Baccalaureate Students				20,000
e. 5 Secretarial—Clerical				34,356
f. 4 Technical, Shop, and Other				19,950
TOTAL SALARIES AND WAGES				266,138
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				23,141
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				289,279
D. PERMANENT EQUIPMENT				24,870
E. EXPENDABLE EQUIPMENT AND SUPPLIES				25,712
F. TRAVEL 1. Domestic (Including Canada)				39,012
2. Foreign				4,100
G. PUBLICATION COSTS				11,700
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				12,166
I. OTHER DIRECT COSTS				576,681
J. TOTAL DIRECT COSTS (C through I)				983,520
K. INDIRECT COSTS 46.2% of $246,184 = $113,736 34.13% of 19,954 = 6,810 $266,138				120,546
L. TOTAL COSTS (J plus K)				1,104,066
Residual Balance at 12/31/74				108,826
M. ~~AMOUNT OF THIS AWARD/AMOUNT~~ Adjusted Request				$ 995,240

REMARKS: Use extra sheet if necessary

*Includes anticipated 10% salary increase

MANAGEMENT
BUDGET SUMMARY

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	John W. Shupe

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. 1 (Co) Principal Investigator(s)			1.0	$ 3,300*
b. ___ Faculty Associates				
Sub-Total				3,300
2. Other Personnel (Non-Faculty)				
a. ___ Research Associates—Postdoctoral				
b. ___ Non-Faculty Professionals				
c. ___ Graduate Students				
d. ___ Pre-Baccalaureate Students				
e. 1 Secretarial—Clerical				9,360
f. ___ Technical, Shop, and Other				
TOTAL SALARIES AND WAGES				12,660
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				1,930
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				14,590
D. PERMANENT EQUIPMENT				
E. EXPENDABLE EQUIPMENT AND SUPPLIES				600
F. TRAVEL 1. Domestic (Including Canada)				3,400
2. Foreign				
G. PUBLICATION COSTS				700
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				
I. OTHER DIRECT COSTS Xerox $600 Communications 600				1,200
J. TOTAL DIRECT COSTS (C through I)				20,490
K. INDIRECT COSTS 46.20% of Salaries and Wages				5,849
L. TOTAL COSTS (J plus K)				26,339
Residual Balance at 12/31/74				0
M. ~~XXXXXXXXXXXXXXXXXXXXXXXX~~ Adjusted Request				$ 26,339

REMARKS: Use extra sheet if necessary

*Includes anticipated 10% increase

NSF FORM 565, JULY 1971 SUPERSEDES ALL PREVIOUS EDITIONS

GEOPHYSICAL PROGRAM
BUDGET SUMMARY

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Augustine S. Furumoto

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. 1 (Co) Principal Investigator(s)			2	$ 5,583*
b. 3 Faculty Associates	16		1	18,780*
Sub-Total				24,363
2. Other Personnel (Non-Faculty)				
a. 2 Research Associates—Postdoctoral	12	9	3	19,245
b. ___ Non-Faculty Professionals				
c. 8 Graduate Students				41,770
d. 8 Pre-Baccalaureate Students				12,800
e. 1 Secretarial—Clerical				9,960
f. 2 Technical, Shop, and Other				14,300
TOTAL SALARIES AND WAGES				122,438
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				10,783
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				133,221
D. PERMANENT EQUIPMENT (For description see individual task budget sheets following Geophysical Program Narrative)				16,050
E. EXPENDABLE EQUIPMENT AND SUPPLIES				20,112
F. TRAVEL 1. Domestic (Including Canada)				22,112
2. Foreign IUGG Meeting, Grenoble, France				2,600
G. PUBLICATION COSTS				7,500
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				5,566
I. OTHER DIRECT COSTS				13,350
J. TOTAL DIRECT COSTS (C through I)				220,511
K. INDIRECT COSTS 46.2% of $105,484 = $48,734; 34.13% of 16,954 = 5,786; $122,438				54,519
L. TOTAL COSTS (J plus K)				275,030
Residual Balance at 12/31/74				90,054
M. ~~AMOUNT OF THIS REQUEST~~ Adjusted Request				$ 184,976

REMARKS: Use extra sheet if necessary

*Includes anticipated 10% salary increase

NSF FORM 569, JULY 1971 SUPERSEDES ALL PREVIOUS EDITIONS

ENGINEERING PROGRAM
BUDGET SUMMARY

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(s)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Paul C. Yuen

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. 1 (Co) Principal Investigator(s)			1.0	$ 2,996*
b. 8 Faculty Associates		4.5	13.0	38,112*
Sub-Total				41,108
2. Other Personnel (Non-Faculty)				
a. ___ Research Associates—Postdoctoral				
b. ___ Non-Faculty Professionals				
c. 6 Graduate Students				26,016
d. 3 Pre-Baccalaureate Students				4,200
e. 1 Secretarial—Clerical				9,036
f. 1 Technical, Shop, and Other				4,650
TOTAL SALARIES AND WAGES				85,010
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				5,784
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				90,794
D. PERMANENT EQUIPMENT (For description see individual task budget sheets following Engineering Program Narrative--Task 3.6)				5,600
E. EXPENDABLE EQUIPMENT AND SUPPLIES				3,600
F. TRAVEL 1. Domestic (Including Canada)				9,400
2. Foreign				
G. PUBLICATION COSTS				3,000
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				6,500
I. OTHER DIRECT COSTS Consultant Fee 500 Communications 1,331				1,831
J. TOTAL DIRECT COSTS (C through I)				120,725
K. INDIRECT COSTS 46.20% of Salaries & Wages				39,275
L. TOTAL COSTS (J plus K)				160,000
Residual Balance at 12/31/74				9,000
M. ~~AMOUNT OF THIS AWARD (ROUNDED)~~ Adjusted Balance				$ 151,000

REMARKS: Use extra sheet if necessary

*Includes anticipated 10% salary increase

ENVIRONMENTAL-SOCIOECONOMIC PROGRAM
BUDGET SUMMARY

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT
BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Robert M. Kamins

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. 1 (Co) Principal Investigator(s)		6	1	$ 21,900*
b. 5 Faculty Associates	1		3	7,480*
Sub-Total				29,380*
2. Other Personnel (Non-Faculty)				
a. ___ Research Associates—Postdoctoral				
b. ___ Non-Faculty Professionals				
c. 1 Graduate Students				1,550
d. 1 Pre-Baccalaureate Students				2,000
e. 1 Secretarial—Clerical				4,000
f. ___ Technical, Shop, and Other				
TOTAL SALARIES AND WAGES				36,930
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				3,461
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				40,391
D. PERMANENT EQUIPMENT Reagent Kits 720 3 Hi.-Vol. Samplers 1080; Electric Fld. Srce 420				2,220
E. EXPENDABLE EQUIPMENT AND SUPPLIES				400
F. TRAVEL 1. Domestic (Including Canada)				2,600
2. Foreign				
G. PUBLICATION COSTS				
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				100
I. OTHER DIRECT COSTS 46.20% of Salaries and Wages				
J. TOTAL DIRECT COSTS (C through I)				45,711
K. INDIRECT COSTS				17,061
L. TOTAL COSTS (J plus K)				62,772
Residual Balance at 12/31/74				9,772
M. ~~XXXXXXXXXXXXXXXXXXXXXXXXXXX~~ Adjusted Request				$ 53,000

REMARKS: Use extra sheet if necessary

*Includes anticipated 10% increase

DRILLING PROGRAM
BUDGET SUMMARY

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROGRAM	Agatin T. Abbott

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. 1 (Co) Principal Investigator(s)			1	$ 3,100*
b. ___ Faculty Associates				
Sub-Total				3,100
2. Other Personnel (Non-Faculty)				
a. ___ Research Associates—Postdoctoral				
b. ___ Non-Faculty Professionals				
c. 2 Graduate Students				2,000
d. 2 Pre-Baccalaureate Students				1,000
e. 1 Secretarial—Clerical				2,000
f. 1 Technical, Shop, and Other				1,000
TOTAL SALARIES AND WAGES				9,100
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				1,183
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				10,283
D. PERMANENT EQUIPMENT Equipment to handle drill cores				1,000
E. EXPENDABLE EQUIPMENT AND SUPPLIES				1,000
F. TRAVEL 1. Domestic (Including Canada)				1,500
2. Foreign On site visitation to Iceland: Airfare-1,100 Per Diem- 200 Internal travel-200				1,500
G. PUBLICATION COSTS				500
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				
I. OTHER DIRECT COSTS (For description see individual task budget sheets following Drilling Program Narrative)				560,300
J. TOTAL DIRECT COSTS (C through I)				576,083
K. INDIRECT COSTS 46.2% of $6,100 = $2,818 34.13% of 3,000 = 1,024 $9,100				3,842
L. TOTAL COSTS (J plus K)				579,925
Residual Balance at 12/31/74				0
M. ~~AMOUNT OF THIS AWARD (ROUNDED)~~ Adjusted Request				$ 579,925

REMARKS: Use extra sheet if necessary

*Includes anticipated 10% increase

NSF FORM 569, JULY 1971 SUPERSEDES ALL PREVIOUS EDITIONS

HAWAII GEOTHERMAL PROJECT
PHASE II PROPOSAL REVISION
MANAGEMENT (1.0)

Management responsibilities remain essentially unchanged from those described in the initial proposal--only at a slightly reduced level. Figure M-I is repeated for ready reference and illustrates the relationship between Management and: a) the four research programs, and b) the three advisory groups.

The revised management budget was decreased from the original figure by a third--from $39,401 to $26,339. This $13,062 reduction came from: 1) Travel - $5,600; 2) Consultants - $2,000; and 3) Student help - $2,026, with lesser savings in communications, publications, expendable supplies, staff benefits and overhead. The elimination of consultants and the drastic decrease in travel funds will curtail interaction with other geothermal programs and minimize the involvement of the National Liaison Board with the HGP--illustrating one of many sacrifices necessitated by the budget reduction.

The revised budget appears as page 1 - 3 in this section and is also included with the budget summaries in the Overview Section.

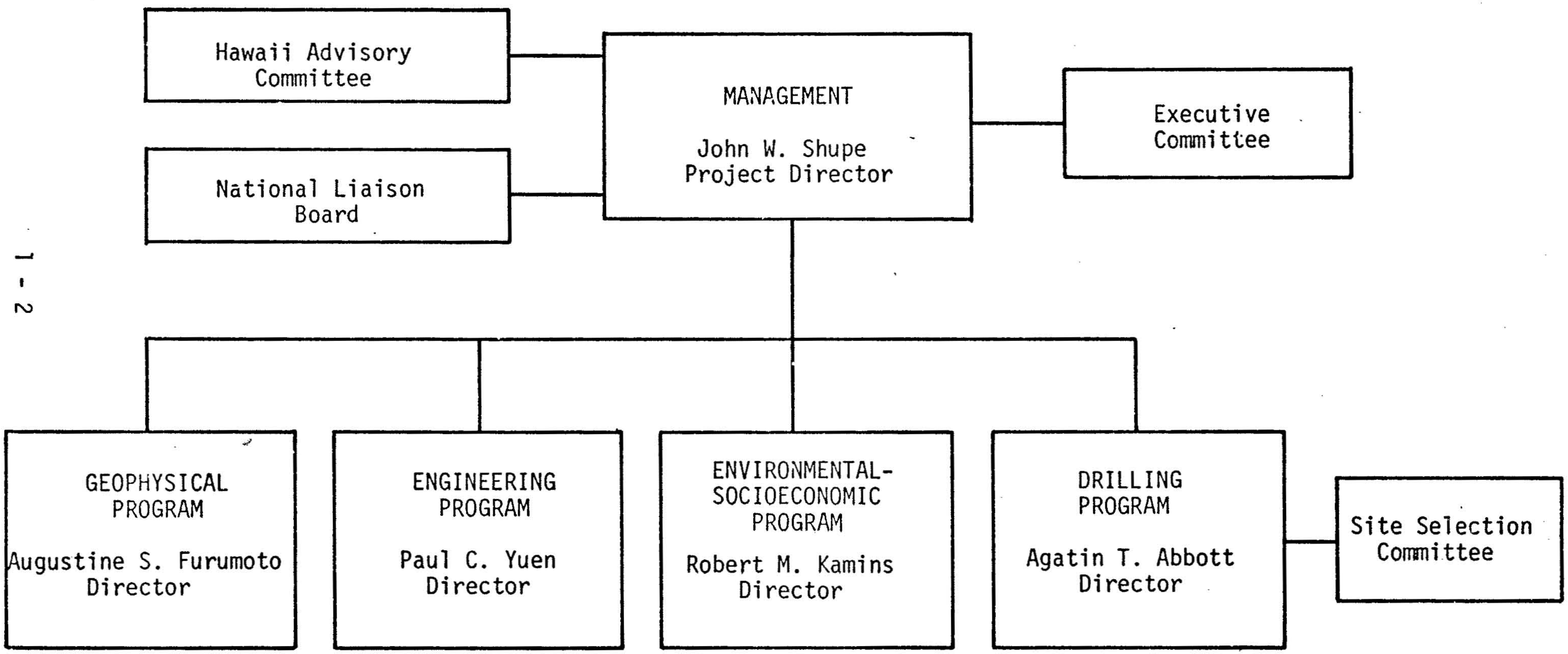


Figure M-I

ORGANIZATIONAL CHART
HAWAII GEOTHERMAL PROJECT - PHASE II

MANAGEMENT
BUDGET SUMMARY

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	John W. Shupe

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. 1 (Co) Principal Investigator(s)			1.0	$ 3,300*
b. ___ Faculty Associates				
Sub-Total				3,300
2. Other Personnel (Non-Faculty)				
a. ___ Research Associates—Postdoctoral				
b. ___ Non-Faculty Professionals				
c. ___ Graduate Students				
d. ___ Pre-Baccalaureate Students				
e. 1 Secretarial—Clerical				9,360
f. ___ Technical, Shop, and Other				
TOTAL SALARIES AND WAGES				12,660
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				1,930
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				14,590
D. PERMANENT EQUIPMENT				
E. EXPENDABLE EQUIPMENT AND SUPPLIES				600
F. TRAVEL 1. Domestic (Including Canada)				3,400
2. Foreign				
G. PUBLICATION COSTS				700
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				
I. OTHER DIRECT COSTS Xerox $600; Communications 600				1,200
J. TOTAL DIRECT COSTS (C through I)				20,490
K. INDIRECT COSTS 46.20% of Salaries and Wages				5,849
L. TOTAL COSTS (J plus K)				26,339
Residual Balance at 12/31/74				0
M. ~~AMOUNT OF THIS REQUEST~~ Adjusted Request				$ 26,339

REMARKS: Use extra sheet if necessary

*Includes anticipated 10% increase

Hawaii Geothermal Project - Geophysical Program

Principal Investigator: Augustine S. Furumoto

A PROPOSAL FOR CONTINUING EXPLORATION IN SEARCH FOR GEOTHERMAL SOURCES IN THE ISLAND OF HAWAII

I. INTRODUCTION: Objectives of the Present Proposal

The following is a proposal to the National Science Foundation, Research Applied to National Needs, to continue geophysical and other exploratory investigations in search for geothermal sources on the island of Hawaii by faculty and staff of the Hawaii Institute of Geophysics (HIG). The program proposed is a continuation of that started in May 1973 under NSF grant GI-38319. Specifically funding is requested:

(a) to process and analyze the geophysical field data gathered during 1973 and 1974;

(b) to initiate two new types of study that are considered necessary for interpretation of the field data;

(c) to carry out a limited amount of field surveys to cover those areas that were omitted in previous surveys for lack of time or funds or both; and

(d) to carry out a drilling program to test interpretation of our data.

The above mentioned activities are considered necessary before embarking on a full scale drilling program to look for geothermal sources at great depths.

At the present time the on going geophysical program consists of seven tasks all housed within HIG. For the calender year 1975, the program will eliminate one task and initiate two more. The task to be eliminated has essentially accomplished its objective with this proposal, since its objective was to look into the cost factor and other questions involving a drilling program.

The proposal is organized into five sections. Section I introduces the overall picture. Section II presents a coherent summary of the geological, geochemical and geophysical tasks and surveys carried out during 1973 and 1974 and explains how the program has arrived at its present status in a step by step logical manner. Section III gives the methods of investigation and results of each task. In Section IV the objective of the program is explained with a coordinated scheme on how this will be attained by contribution from each task. Section V will contain brief descriptions of each individual task.

With the completion of the work as outlined in the proposal the exploratory phase of the project will come to a conclusion. The answer will be given as to whether there exists a geothermal source utilizable by present day technology, and if the answer is affirmative, an estimate of the available power of the source and its expected longevity will be made. It should be emphasized that the responsibility laid to this project by NSF monitors is to find utilizable resources. Hence estimates of hot rock capacity or magma reservoir are not within the perview of this proposal.

Should a utilizable geothermal source be found the geophysical program can proceed to the next responsibility of monitoring the reservoir and the environment to forestall ecological damage.

SECTION II A SUMMARY OF EXPLORATORY SURVEYS CARRIED OUT DURING 1973 AND 1974

Upon receipt of Grant GI-38319 from the National Science Foundation and matching grants from the State of Hawaii and the County of Hawaii, the geophysical program was initiated by carrying into action a plan already formulated. But as with all plans, alterations had to be made due to circumstances that could not be foreseen, such as late delivery of instruments by manufacturers. The exploration program, however, was carried out according to the flow chart given in Figure 1. The flow chart indicates the sequence of various tasks and the names of the persons in charge of the tasks. On the right of the flow chart are given the times during which the tasks were carried out.

It should be pointed out that in the flow chart are two distinct electrical surveys, one carried out by George Keller of the Colorado School of Mines and the other by Douglas Klein of HIG. The distinction will become apparent in the discussions that follow.

The planning and coordination section took care of coordinating the program in many facets, such as equipment purchases, assignments of students to tasks, logistics of the field work. The geophysical team worked smoothly and in the field there was much intertask cooperation and assistance. An electronic technician attached to this section had the responsibility of assembling equipment and instruments according to the specifications spelled out by the various task leaders. The section also included an administrative clerical assistant to handle purchasing, typing, filing, and intertasks communications.

Literature surveys on past geological, geochemical, and geophysical investigations on the volcanoes of the island of Hawaii began as soon as the program was funded and continued throughout 1973 and 1974 even while the field surveys were going on. Three reports are now nearing completion, one each to cover geology, geochemistry and geophysics of the east rift of Kilauea volcano. As several authors cooperated on these reports, no one person can be said to be responsible for the literature surveys.

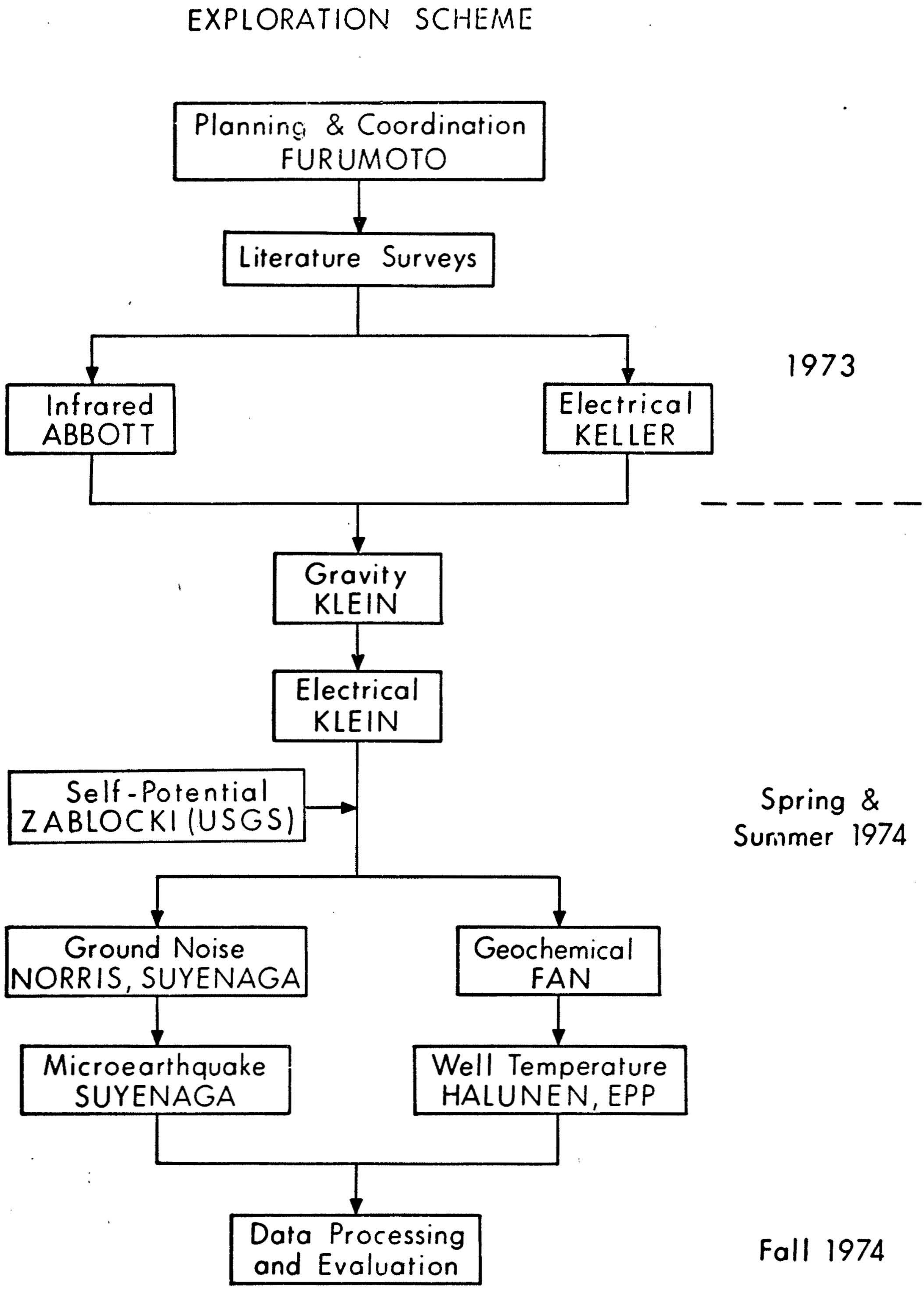


Figure 1. Exploration Program Carried Out During 1973 and 1974

The infra red scanning survey by aerial photography with A. T. Abbott in charge was launched in early summer of 1973 to survey the rift zones of Kilauea, Mauna Loa and Hualalai volcanoes. (See Figure 2 for locations of volcanoes and rift zones.) The survey showed that possible thermal anomalies existed on the east rift and southwest rift of Kilauea and the southwest rift of Mauna Loa. The rift zones of Hualalai looked unpromising.

Because of the existence of fumaroles and steaming vents, it is quite obvious even to a casual observer that the east rift of Kilauea contains spots of thermal anomalies. Also, the east rift was the scene of profuse eruptions in 1955 and in 1960. For these reasons even before the results of the infra red survey were in, it was decided to carry out electrical resistivity survey over that part of the east rift that is not included in the National Park. This meant surveying what is geographically known as the Puna District of Hawaii. As the capability for electrical resistivity surveys did not yet exist at the Hawaii Institute of Geophysics, G. V. Keller of Colorado School of Mines was contracted to carry out reconnaisance type surveys over the Puna District and over a small area near the summit of Kilauea volcano.

Keller used the dipole-dipole method and covered very nearly all of Puna District in four weeks. His results showed that there were three areas on the east rift zone of Kilauea where the subsurface resistivity was anomalously low compared to other areas. (Figure 3). As these areas of anomaly will arise frequently in our discussions we shall name them the Kapoho anomaly, Pahoa anomaly and Opihikao anomaly, according to their geographical locations.

Keller then proposed a two layer model of resistivity for the Puna District. According to him the first layer had a resistivity of 10 - 20 ohm-m

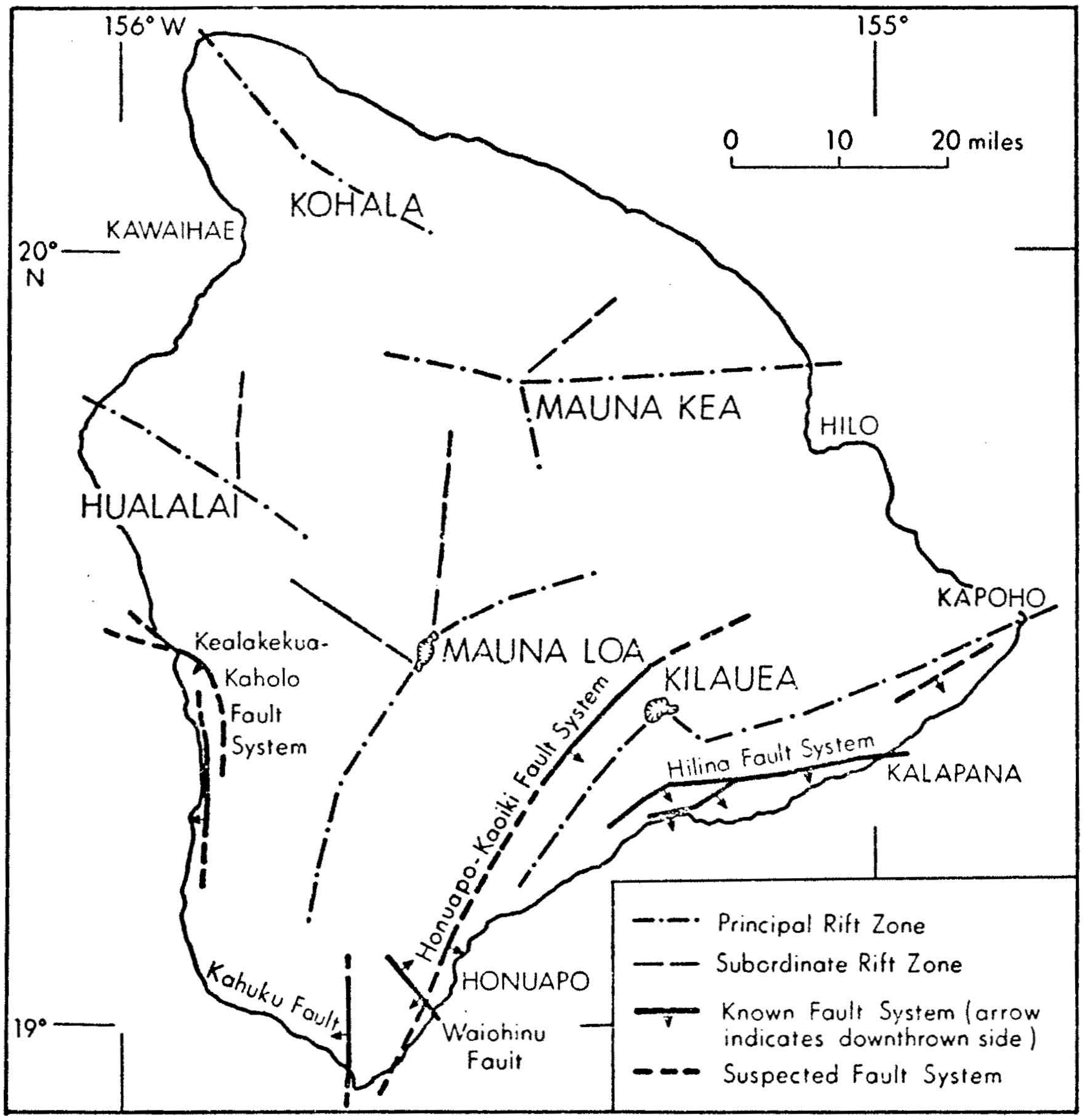


Figure 2. The Island of Hawaii with Some Geological Features

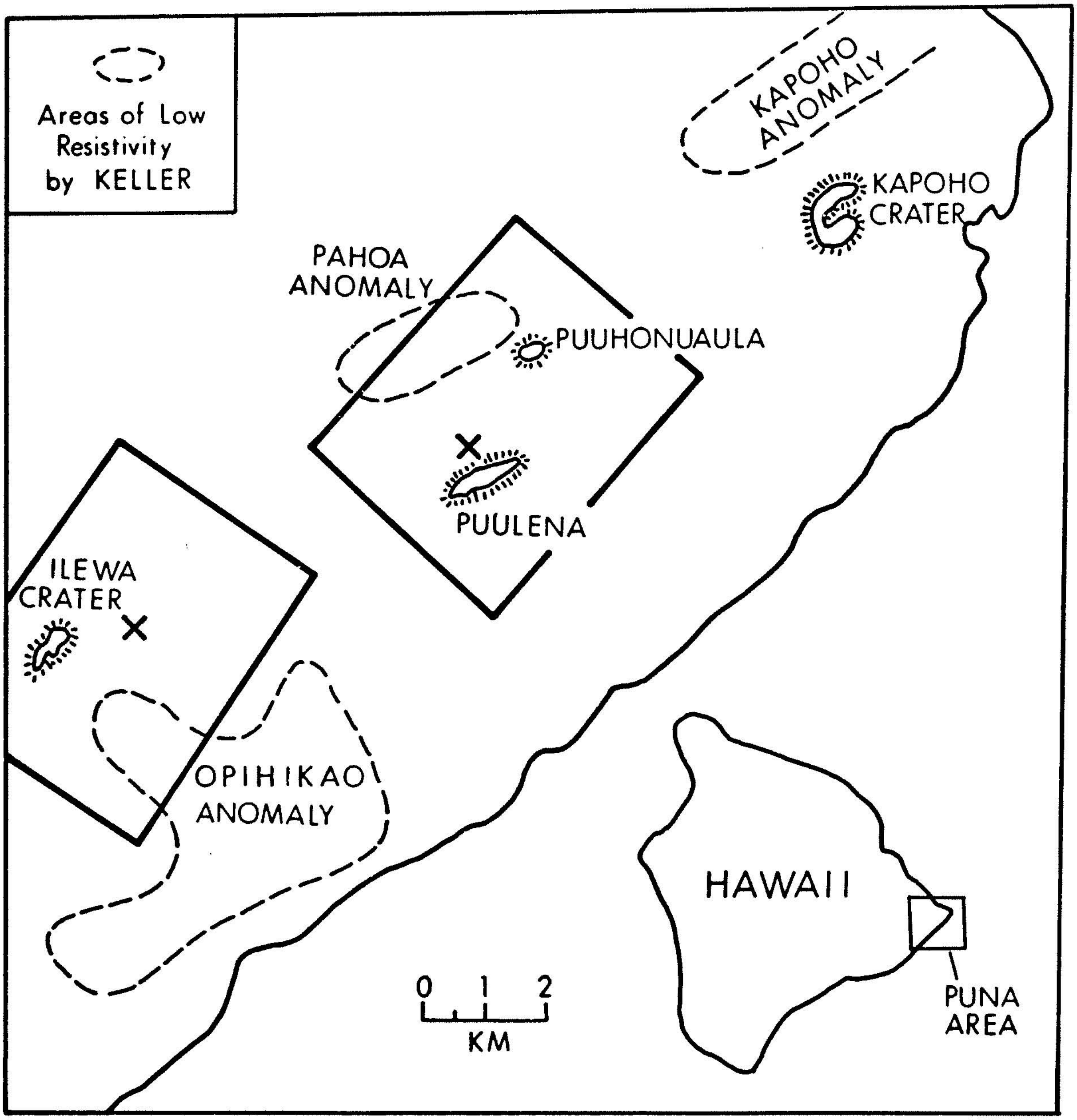


Figure 3. Puna District with Electrical Resistivity Anomalies. The blocked areas are locations of Figures 8 and 9.

extending from ground surface to a depth of 700 m; the second layer had a resistivity of less than 10 ohm-m and extended from 700 m depth to a depth of 2200 m. Below 2200 m he assumed the resistivity to be infinite. The low resistivity of the second layer was explained by Keller as a rise in electrical conductivity of briny ground water due to high temperature.

During the summer of 1973 the electical survey task of HIG with D. Klein in charge was busy assembling and testing equipment. An attempt was made at field surveys in the Puna District but instrumental failure plagued the team. Also during the summer of 1973 the seismic task set up a tripartite geophone array over the Opihikao anomaly, but hardly any earthquake was detected originating from the anomaly.

During the spring of 1974 Klein carried out a gravity survey over a portion of the Puna District to see whether the dikes associated with the rift zone were dipping or not. The results were inconclusive.

The summer of 1974 saw a proliferation of field activities on the part of faculty and staff of the Hawaii Institute of Geophysics. Several teams were usually in the field simultaneously.

The electrical survey team had to use several different methods, depending on the depth of penetration desired. The details of this are given in the task description. One side result of the survey was the knowledge of limitations of electrical methods when applied to Hawaiian basaltic rock. From the results of the electrical surveys, it became obvious that the east rift of Kilauea, namely the Puna District was the most promising for geothermal sources. It was decided on the strength of electrical surveys that henceforth investigation should concentrate on the Puna District. The southwest rift of Kilauea may contain a thermal anomaly but it is much, much less promising than the east rift.

During the early summer of 1974, a few persons from HIG assisted Charles Zablocki of the U.S. Geological Survey in carrying out a self-potential electrical survey over the Puna District. In return the data were made available to the HIG exploration group. For this reason in the flow chart of Figure 1 the self-potential task is shown to be contributed from an external source. The results showed that a self-potential source of +500 millivolts existed close to the Pahoa anomaly and a +900 millivolt source existed close to the Opihikao anomaly. The Kapoho anomaly showed no signs of a self-potential source.

Throughout the island of Hawaii are numerous wells drilled for irrigation and other purposes, with quite a few in the Puna District. As part of the geochemistry task, water samples from these wells throughout the islands were gathered and analyzed for oxygen isotope ratio, by P. F. Fan and Gary McMurtry. One preliminary inference from the data is that the water in some of the Puna wells came through a hot regime of about 200°C. The full implication of the geochemical surveys has not been arrived yet at the present writing.

The temperature distribution with depth of these wells were measured by J. Halunen and D. Epp. A well near the Pahoa anomaly showed a temperature of 93°C at the top of the water table. The temperature however decreased rapidly after a few meters below the water table, an indication of convective motion of water from a hot source. Within the Opihikao anomaly area a well showed a temperature of 100°C but the well was unfortunately not deep enough to reach water table.

The seismic survey task consisted of two parts. One was the ground noise survey done by W. Suyenaga and R. Norris whereby the level of ambient ground vibrations was compared from place to place. Very early unrefined results show that the 8 hz band of ground noise seems to center around the Pahoa anomaly. The level of lower frequency bands decreased consistently when one went away from the seashore and towards the interior of the island, indicating that for these bands the noise source was the surf action on the rugged cliff coasts. The other part of the seismic task was to monitor microearthquakes over anomalous areas by setting up an array of seismic stations. Because of late delivery of components from the manufacturers, W. Suyenaga had time enough only to set up the array over the Pahoa anomaly and record for two and half weeks. Several earthquakes per day were recorded, and the seismograms are now being processed to locate the epicenters and foci. A preliminary result show that microearthquakes are associated with the rift near the anomalies. The depth of the foci ranges from 3 to 15 km.

In brief summary, the following sequence of surveys narrowed down prospective geothermal sites to two locations. The infra red surveys suggested areas on the east and southwest rifts of Kilauea and the southwest rift of Mauna Loa as prospective sites for further investigations. The electrical surveys by Klein indicated that the east rift of Kilauea was much more likely as a prospective area than the other two rifts. Keller's electrical survey narrowed down the east rift to three areas and Klein's work confirmed Keller. The self-potential survey by Zablocki showed that of the three areas, the Pahoa anomaly and the Opihikao anomaly were spots of subsurface activity. Preliminary ground noise survey says that the Pahoa anomaly is more active than the Opihikao anomaly, although the ground noise data need more scrutiny. Well temperature measurements and geochemical surveys say that both Pahoa and Opihikao anomalies should be examined.

SECTION III RESULTS OF INDIVIDUAL SURVEYS

Condensed forms of the results of the following surveys are presented in this section.

(1) Infrared scanning survey

(2) Electrical resistivity survey by Keller

(3) Electrical resistivity survey by Klein

(4) Self-potential survey

(5) Microearthquake and microseismic surveys

(6) Gravity surveys

(7) Well temperature survey

Results of geochemical surveys are not given as results have not been collated. Oral reports on this survey have been included in parts of this proposal.

1. Infrared Scanning Survey

Investigator: A. T. Abbott

INTRODUCTION

From July 31 through August 4, 1973 night time flights for obtaining infrared imagery along the east and southwest rift zones of Kilauea and the southwest rift zone of Mauna Loa were undertaken on the island of Hawaii. Flights were also made on Haulalai and Kohala volcanoes, but because of inconclusive results are not included in this report. Ground control stations had been established during daylight hours several days prior to starting the flight program. Students stationed at the ground central points guided the aircraft on predetermined flight paths by the use of directional lights which were visible to the plane's navigator. Results of the infrared scanning program are considered to be very successful. Events leading up to the final imagery on 8 x 10 color prints will be discussed below.

The sum of $23,900 was designated by the NSF to be expended on aerial photogeologic work on the Hawaii Geothermal Project. Infrared scanning was the only aerial technique employed in this phase.

A firm specializing in infrared surveys, Daedalus Enterprises of Ann Arbor, Michigan was selected as best equipped and experienced in Hawaiian conditions to accomplish the infrared imagery survey. Towill Engineering Corporation of Honolulu provided the aircraft, pilot and navigator and submitted a report with maps and black and white aerial photographic mosaics. These firms earlier the same year had flown paths for Dr. George Keller of Colorado School of Mines, who was engaged in locating a deep drill hole near the summit of Kilauea.

FLIGHT PATHS AND DESCRIPTIONS

(1) East Rift Zone of Kilauea

Two long parallel flight paths were flown along the East rift zone from points outside the boundary of Hawaii Volcanoes National Park to Cape Kumukahi. Shorter paths crossing the two long parallel lines were flown at the intersection of the rift zone with the main highway between Pahoa and Kalapana. Approximately 35 line miles of usable record was obtained. From this the following strips were selected for reproduction in infrared false color imagery:

Three miles of light paths high on the rift zone at an average ground elevation of 2100 feet provide excellent examples of rift lineation and temperatures aureoles. The DIGICOLOR prints showed a temperature range of 14°C to 20°C. Numerous sites along the rift showed spots of white color indicating the temperature exceeded the highest range on that temperature set. This is not surprising in view of the fact that wisps of steam are issuing from some of the vents probably as a result of meteoric water coming in contact with residual heat of lavas from the 1966 eruption in this area. Downslope from the steam vents, a fairly extensive area shows a slightly higher surface temperature than its surroundings, by an average of 1°C.

The area for the second set of DIGICOLOR prints in the Kilauea east rift zone was selected from a flight path of approximately two miles in length across the area of intersection of the rift zone and the Pahoa-Kalapana highway at a ground elevation of approximately 300 feet. The temperature range of this path is 16°C - 25°C or 1.5°C per color. Again numerous sites showing white along the rift zone indicate local hot spots and an aureole of decreasing temperatures are distributed outward from the rift. Fine examples of surface temperature zones is demonstrated in this imagery.

(2) Southwest Rift Zone of Kilauea

A flight path 12 miles long was followed from the point of intersection of the western boundary of Hawaii Volcanoes National Park and the main highway between Kilauea summit to Pahala to a point on the seacoast approximately 4 miles east of Punaluu.

The altitude maintained was about 3000 feet above ground level. Throughout most of the strip a thermal anomaly was evident along the Great Crack. The temperature range on the flight path was 18°C - 22°C. Of unusual interest on this path is a thermal anomaly in a target-like pattern near the southern end of the Great Crack approximately 1 1/4 miles from the coastline at an elevation of 300 feet above sea level. The target-like pattern is 1200 feet wide, 1600 feet long. The roughly circular pattern of thermal anomaly lies 600 feet northwest of a splinter extension of the Great Crack. The highest temperature within the target area reaches the red color or 22°C in two small spots, and within the Great Crack extension, small local spots reach white, or off scale.

The anomaly appears to be associated with the lower slopes along the south side of Puu Kolekole, a prehistoric cinder cone, and with the extension of the Great Crack.

This surface thermal anomaly as registered by infrared scanning imagery should receive careful attention as a potential area for further geophysical investigation and possibly research drilling.

(3) The Southwest Rift Zone of Mauna Loa

A flight path with the total length of approximately 22 miles followed the southwest rift of Mauna Loa from an elevation of approximately 7000 feet above sea level to the tip of South Point. Only the lowest five mile section of this path to the tip of South Point showed any significant thermal anomalies. This portion has been reproduced in DIGICOLOR and prints developed.

The temperature range on one subset is 16°C -22°c. Thermal anomalies appear along the cliff face of the Kahuku fault as clusters along the base of the cliff and as linear features possibly indicating bedding planes in the lava flows. Numerous spots along the cliff register red and a few local areas show white, or off scale.

The cause of these anomalies is not known at the present time. The Kahuku fault scarp, which reaches 400 feet in height in this area, faces west. Consideration must be given to the possibility that the anomalies result from residual late afternoon solar heat. The imagery was taken at 0030 hours in order to reduce the effect of residual heat. The physical distribution of the warmer areas does not appear to show a pattern that might be caused by residual heating, nonetheless this factor must be kept in mind.

Another, more intriguing possibility lies in the concept that heat may be rising from depth along the plane of the Kahuku fault and issuing at the base of the cliff and along bedding planes of the lava flows. The Kahuku fault is a major structural feature of Mauna Loa shield volcano. It extends ten miles inland from the coast and has been followed out to sea for a distance of over 15 miles. Depth recordings made on board the R/V VALDIVIA in 1973 while steaming past the extension of the fault 4 miles off shore registered a vertical displacement along the fault plane of 1900 meters.

Further geophysical and geological work should be concentrated in the section of the lower portions of the Kahuku fault. This may have promise as an area in which to locate an array of research drill holes.

Also of interest along the South Point shoreline as registered by the infrared imagery is the temperature distribution in the sea water. Directly offshore a large patch of water shows as a white area indicating that its temperature is greater than 22°C. It is not recognized at this time whether this is a bay of warm surface water brought in by ocean currents or wind or whether the warming is caused by some other process.

Infrared Scanning Survey

Task 2.1

A. T. Abbott

With attention focusing on the lower portions of Kilauea east rift zone, infrared scanning imagery in that area was printed and enlarged for study.

Significant in the location of the drill hole location north of Puuleua crater, which is the largest pit crater on the lower rift, is the indication of a small spot of higher temperature on the south rim of the pit crater. It is not an overwhelming beacon, but does indicate perhaps a seepage of heat that may underlie the crater area.

2. Electrical Resistivity Surveys

Investigator: G. V. Keller
Report by: A. S. Furumoto

The electrical resistivity surveys by George Keller were done in June and July 1973 and a report entitled "An Electrical Resistivity Survey of the Puna and Kau Districts, Hawaii County, Hawaii" was submitted by him. The method he used is known as the dipole mapping method. In short, using existing well casings as dipole sources, he caused a large amount of current to flow into the ground, then with a pair of probes the area around the dipole source was surveyed to measure variations in voltage and current. With that, resistivity of the ground between the dipole source and probe is determined. The survey in effect gives an integrated picture of resistivity with respect to depth. Hence the method is a good reconnaissance tool.

The survey came up with three promising areas (Figure 3), the anomalies of Opihikao, Pahoa and Kapoho, along the east rift of Kilauea.

Keller also attempted a depth vs. resistivity interpretation from his data. The profile resulted in a two layer model; the first layer extending from surface to an average depth of 700 m with resistivity about about 20 ohm-m; the second layer extending from 700 m to 2300 m depth with resistivity about 5 ohm-m; and below that a half space of very high resistivity. Keller attributed the low resistivity in the second layer to high temperature.

3. Electrical Resistivity Survey

Investigator: D. P. Klein

Geoelectric reconnaissance surveys in the regions of most promise for geothermal resources on the Island of Hawaii (See Fig. 4) have located no other targets of generally low resistivity as favorable as the lower East Rift of Kilauea which we call the Puna Anomaly. Further work was therefore concentrated on the Puna Anomaly to attempt to determine the vertical resistivity profile and to map the horizontal variations in resistivity.

Keller's results, Fig. 5, provided the first general geoelectric picture of Puna. Note the general regions of low apparent resistivity (less than 5 ohm-m) anomalies I, II and III, as well as the general resistivity-depth profile (20 Ω-m to 600 m, 5 Ω-m from 600-2000 m, high resistivity below 2 km). However, problems arise in dipole mapping where large horizontal resistivity contrasts exist because apparent resistivities are generally a function of source location. Therefore, it was our goal to test the results using inductive techniques. Inductive methods tend to smooth off the effects of lateral inhomogeneities and we expected to obtain a mean resistivity for the depth of penetration at each site. By varying the depth of penetration by station spacing or frequency, an estimate of resistivity-depth may be obtained and by making measurements at many sides horizontal maps of conductivity for a given penetration depth may be obtained. Since inductive methods are not sensitive to resistive media, it was also decided to establish a few schlumberger soundings to establish the electrical properties of the basaltic rocks above sea level. Also, to investigate the

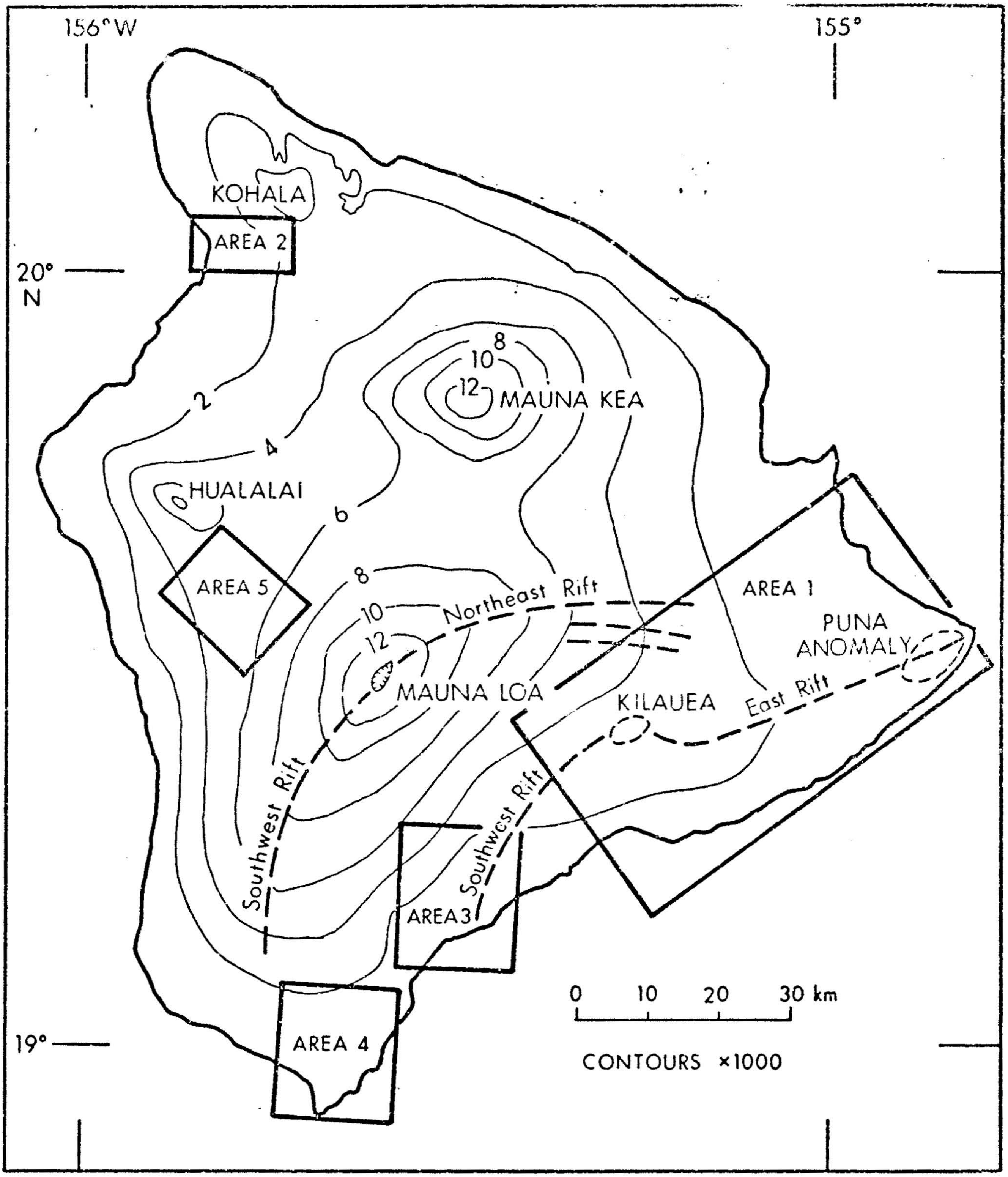


Figure 4. Areas Surveyed by Electrical Methods

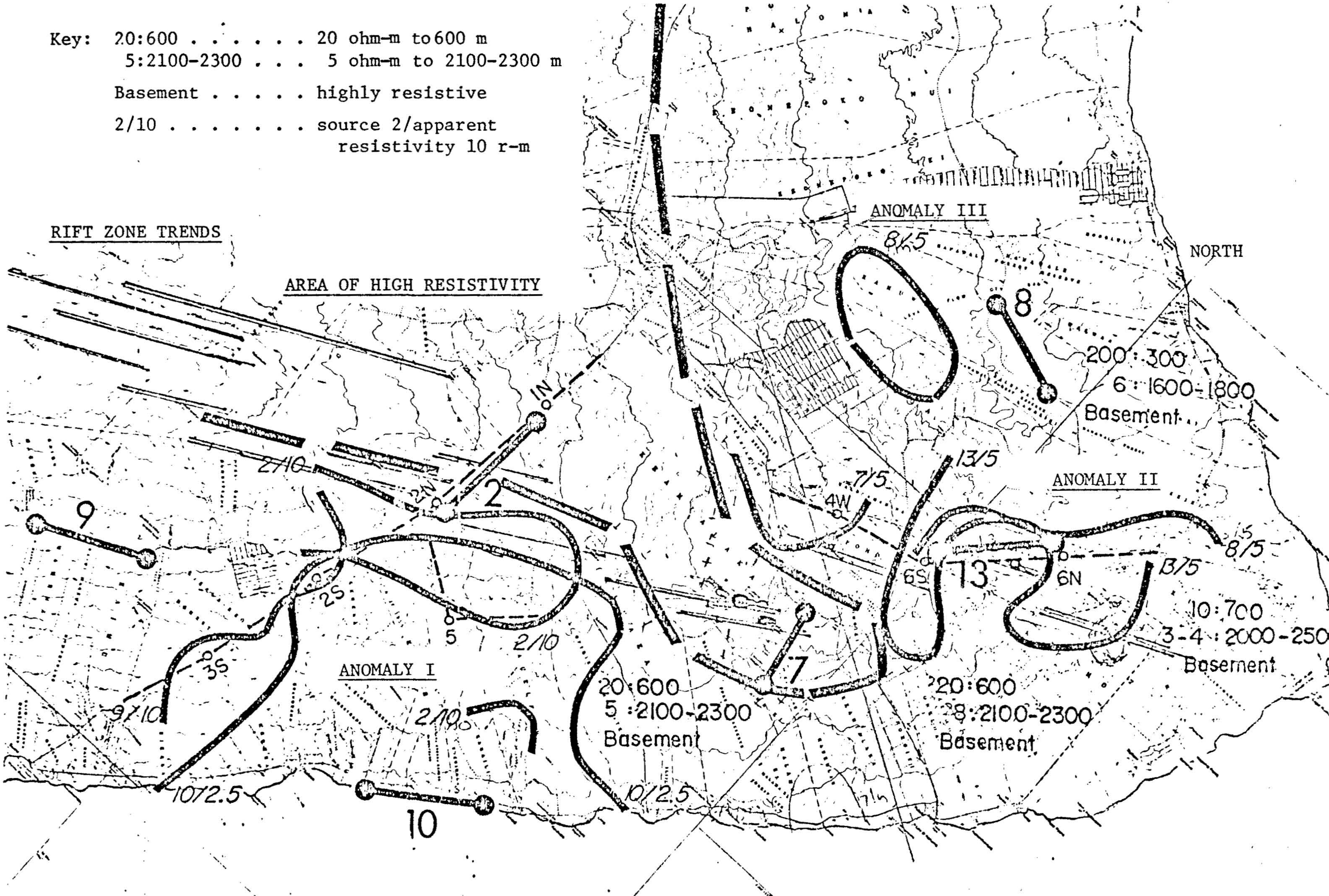


Figure 5, Map of the results of the Reconnaissance Survey of Puna, from G. V. Keller.

lateral variations in the thermal realm, a fine scale mapping of the self-potential field was undertaken by C. Zablocki of the U.S.G.S. with support from the Hawaii Institute of Geophysics.

The formal data analysis of our surveys are now being carried out by J. Kauahikaua, a graduate student at the Hawaii Institute of Geophysics. Thus, we are not yet prepared to present any detailed interpretations. However, we do have a preliminary depth resistivity profile for the regions seaward and landward of the rift (see Fig. 6).

In Fig. 6, the upper control point, above sea level, and the sea level control point are based on loop-loop induction data. The deep control point at roughly 850 m is based on line-loop induction data. The limiting horizontal and vertical bars refer respectively to the spread of calculated resistivities and estimated depth of penetration. The data points in the deep zone are plotted as apparent resistivities versus half-spread for several measurements of the line-loop system. The data points marked by squares are those generally in and above region I (see Fig. 5). The anomalously low resistivity at sea level below the rift implies a thin layer of warm water which is verified by well data and thermal probes.

The deeper resistivity data deserves comment in terms of probable geothermal potential even at this point in analysis. Taking the lower limit of resistivity, 5 ohm-m, and a typical porosity of Hawaiian rocks, 10%, we can estimate the fluid resistivity from Archie's law

$$\rho \text{ fluid} = \rho \text{ bulk} \times (\text{porosity})^2$$

as .05. If the rock is saturated with sea-water (ρ = .25 at 18°C) the expected

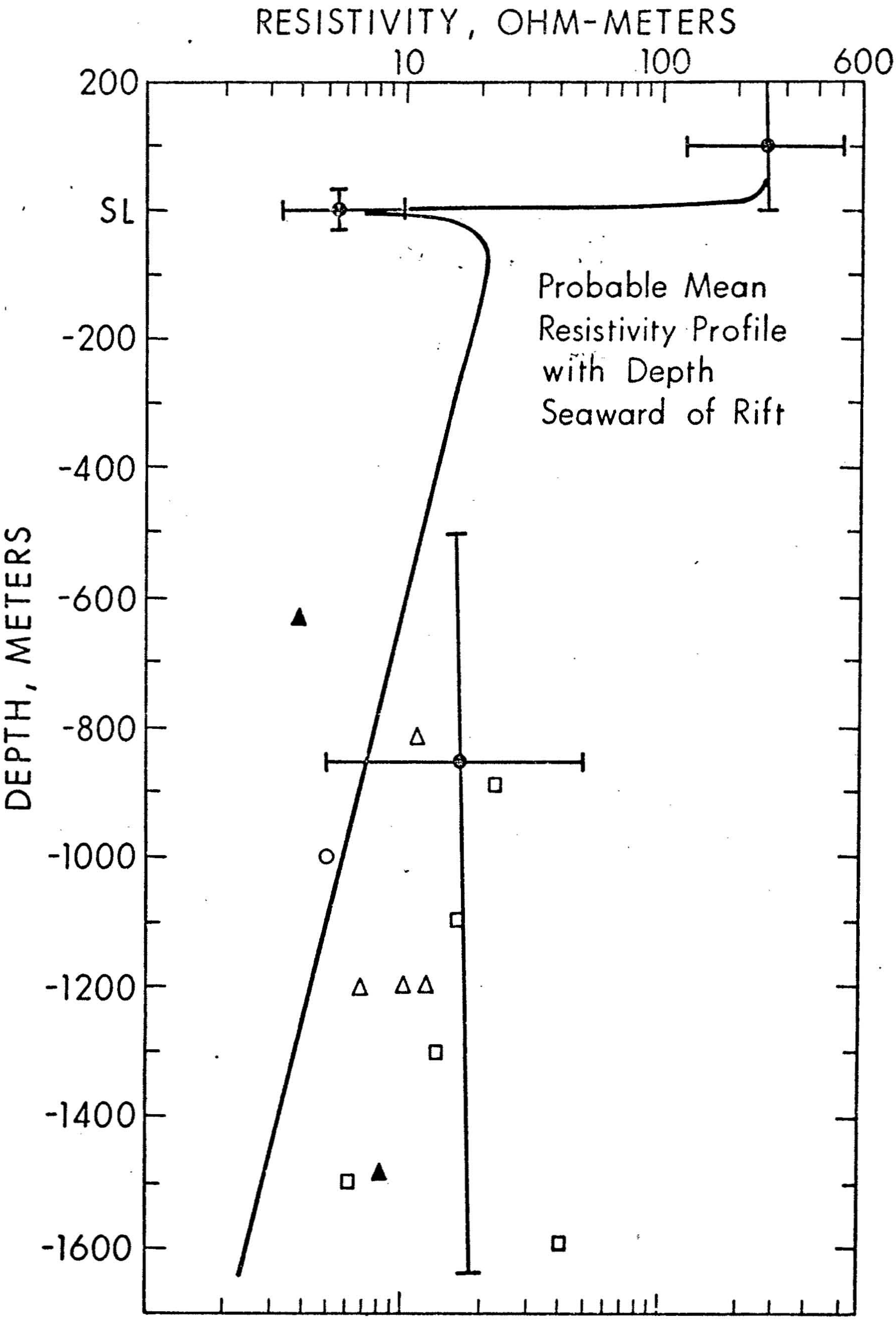


Figure 6. Resistivity-Depth Profiles for Puna District

temperature is about 180°C. The uncertainties in porosity and salinity, however, made this estimate of temperature rather hazardous. If porosities of closer to 25% as the test hole on Kilauea indicates, the temperature would be considerably lower. There is, however, no real basis for direct comparison between the rocks of Puna at 800 m depth and those of the Kilauea Summit. The Puna rocks at this depth were probably extruded beneath the sea which would tend to make their porosities less.

The fluid salinity is also a guess, Puna well data all show fluids with salinities less than half that of seawater. If salinities less than seawater extend to depth, the temperature estimate could be considerably increased. Only drilling data can resolve these questions. Nevertheless, from the standpoint of our present position, the temperature profile is summarized in Fig. 7. (Also shown is the boiling point curve.) Although the mean temperature curve is not close to the boiling curve there is the optimistic possibility that in the anomalous region the temperature gradient would be considerably higher.

Future plans include several intermediate depth soundings over the specific areas of the anomalous geoelectric data to attempt to provide more quantitative estimates of the above possibility. Further analysis of the present data, including the self-potential work being work on by C. Zablocki, should outline in detail those areas of most probable anomalous temperature conditions.

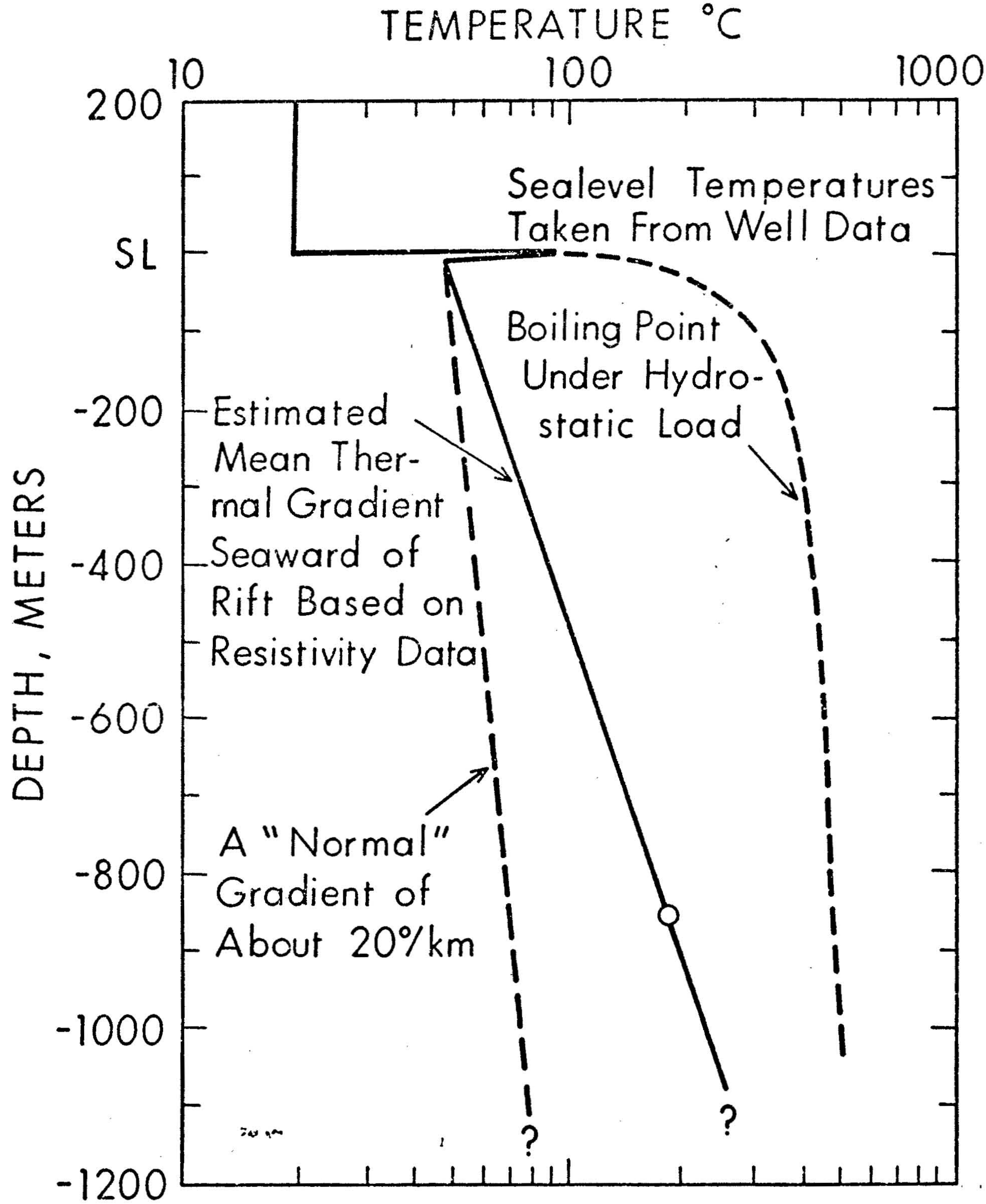


Figure 7. Temperature-depth Profile

4. Electrical Self-Potential Survey

Reporter: A. S. Furumoto

C. Zablocki of the Hawaii Volcano Observatory, United States Geological Survey, has been carrying out self-potential surveys over the various parts of the island of Hawaii for the past few years. His field method was the usual one of using porous pots as electrodes and a high resistance voltmeter to measure potential differences. An agreement was made with Zablocki so that Hawaii Institute of Geophysics will provide field personnel to assist him in surveys over the Puna Area, in exchange for which the self-potential data will be made available to HIG.

The self-potential surveys revealed two areas of prominent potential differences, one in the Pahoa anomaly area and the other in the Opihikao anomaly area.

Figure 3 shows the locations of self-potential anomaly maps, while Figures 8 and 9 show the contour maps of the potential differences of the Pahoa and Opihikao anomalies respectively.

Consider the Pahoa anomaly map of Figure 8. A prominent positive pole of +500 mV exists near the center with a relative negative pole of +150 mV near by and other relative negative poles of 0 mV in other spots.

Although not shown in the contour maps, the potential difference along the shoreline south of both anomalies rose to a value of +350 mV. When a cross section of the potential differences is plotted through the Pahoa +500 mV and +150 mV poles and extended to the sea shore, the result will look as shown in diagram I of Figure 9A.

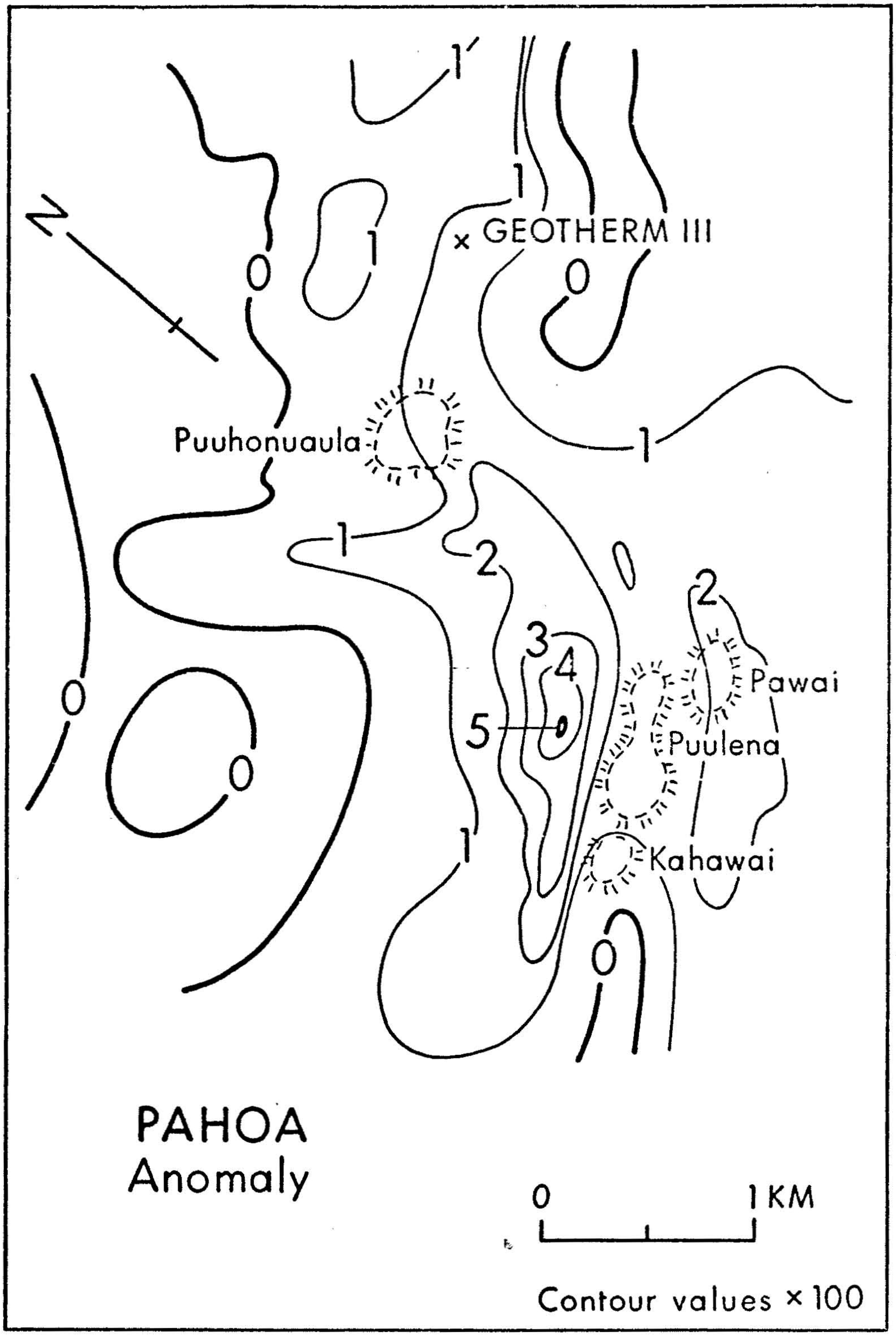


Figure 8. Self-Potential Field over Puna Anomaly

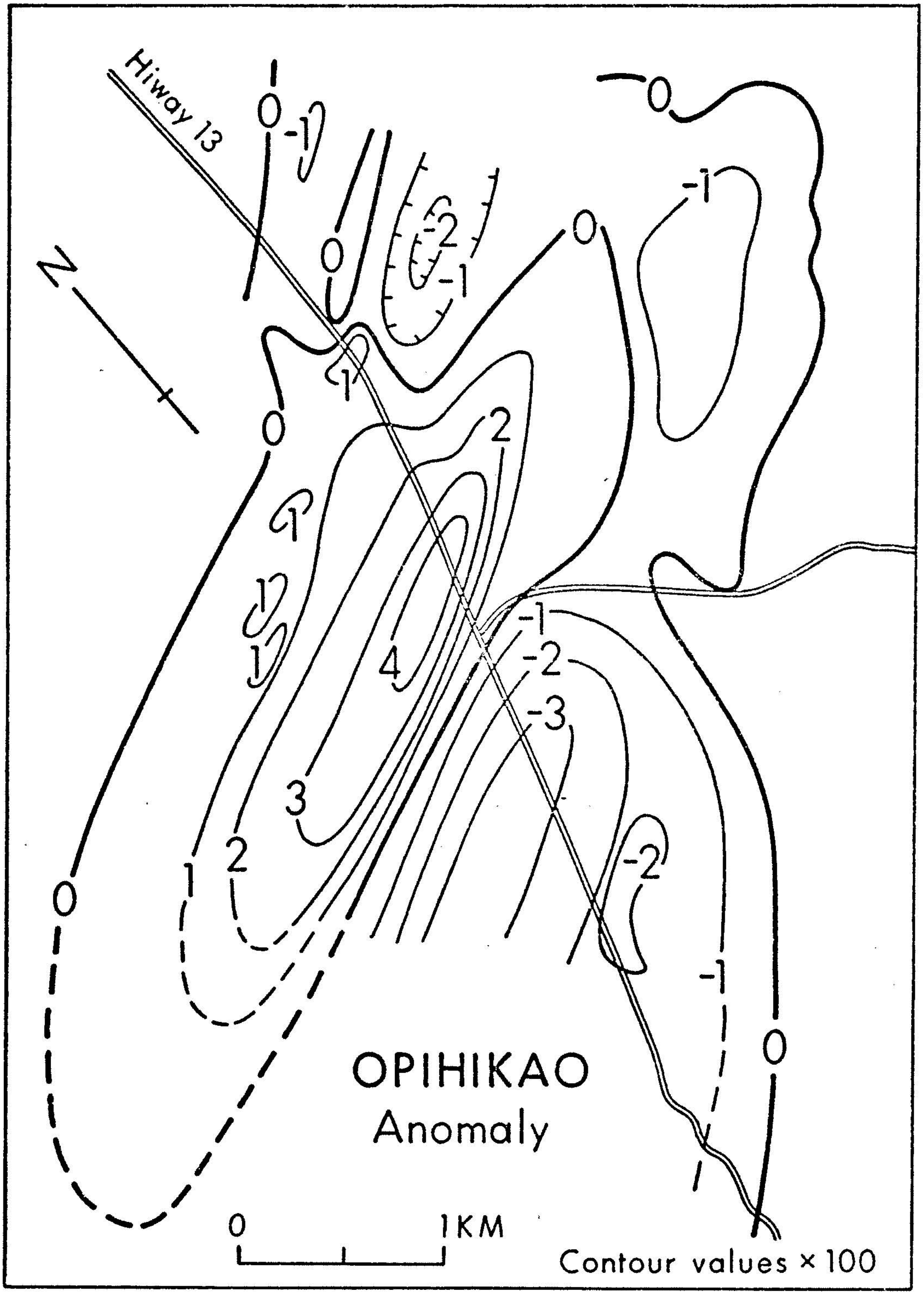
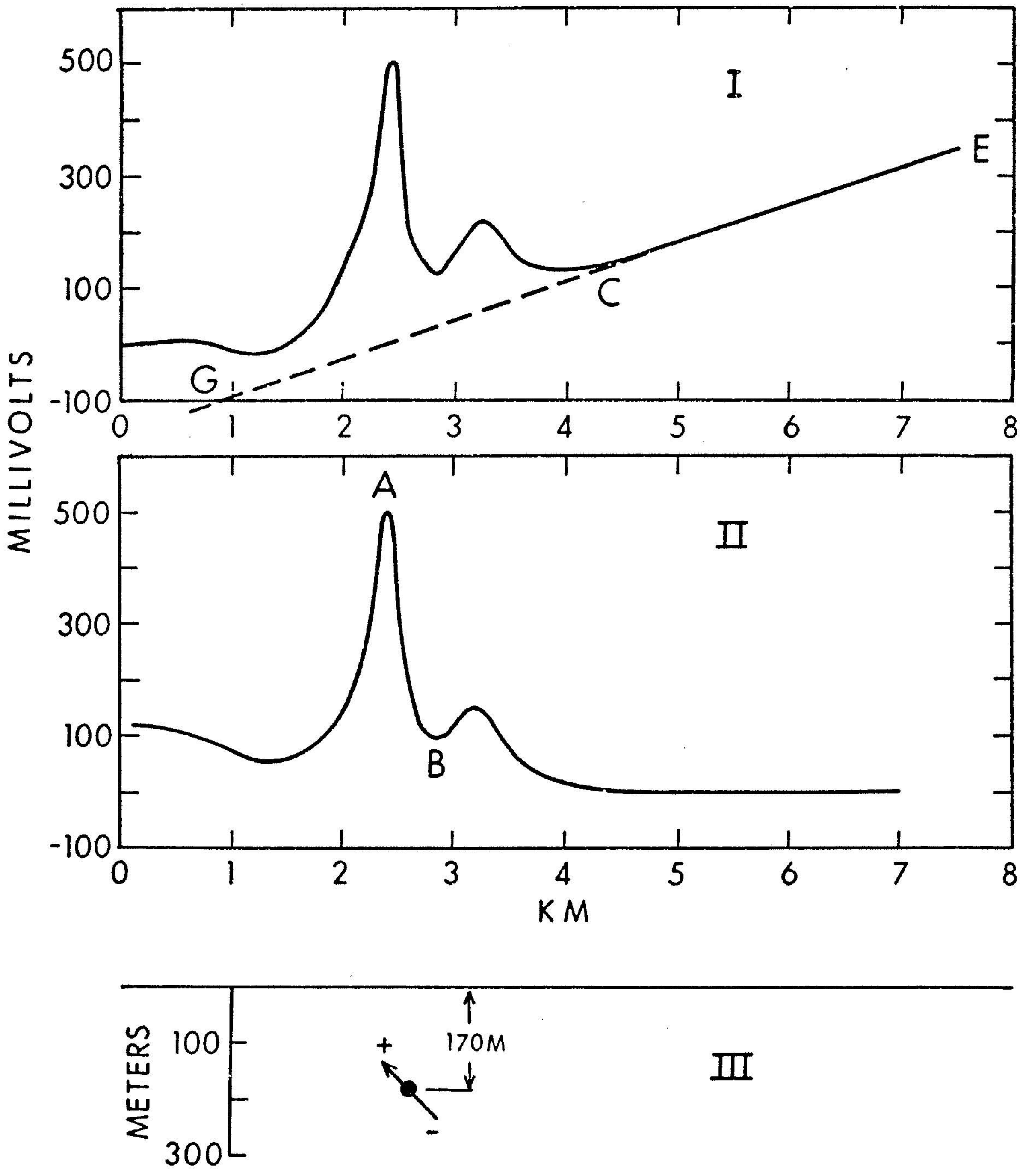


Figure 9, Self-Potential Field over Opihikao Anomaly



SELF POTENTIAL PROFILE AND INTERPRETATION (see Text)

Figure 9A

The classical method to interpret the data of diagram I is to consider CE part of the curve as due to a regional trend which can be represented by the line EG. If the regional trend is substracted out, the self-potential curve due to the anomaly will look as given in diagram II. When the curve of diagram II is analyzed by deWitte's method (1949) by considering A as positive pole and B as negative, a dipole source at a depth of 170 m dipping 50° in the direction S42°E can be considered as causing the anomaly. This depth of 170 m puts the dipole source right at the water table. On the other hand, the Opihikao anomaly is due to a dipole source at 660 m depth, dipping 60° in the S15°W direction. As the water table in the Opihikao area is about 270 m deep, the electrical dipole is about 390 m below the water table.

Several hypothesis can be advanced as possible explanation of the self-potential source: (a) oxidation of sulfur compounds, (b) Nernst effect from a hot dike, (c) streaming potential, and (d) dilute solution of magnesium and calcium in cracks. These will be discussed separately in the following paragraphs.

In mineral exploration, self-potential anomalies are explained in terms of oxidation of sulfides to sulfates, which can produce an electrical potential of 0.8 volts. Oxidation potentials are usually found in nature as prominent negative poles, while we have a prominent positive pole. Nevertheless Sato and Mooney (1960) cited an example where oxidation of sulfides was manifested as a positive pole. We cannot cavalierly rule out the possibility that the self-potential anomaly is being caused by a subsurface sulfur bank.

The Nernst effect is a phenomenon in which heat flow occurring in a magnetic field causes an electromotive force to be set up. The directions of the magnetic field, heat flow and electromotive force are mutually perpendicular. The possibility of a Nernst effect electromotive force exists here as the self-potential anomaly sits right on top of the rift zone. In the presence of a geomagnetic field, a heat flow away from a very hot dike can cause the anomaly.

Unfortunately the Nernst effect is little understood even in physics with very little published data on the Nernst coefficient. The Nernst coefficient for bismuth gives a right order of magnitude for the observed electromotive force and expected temperature gradient, but rocks are not bismuth. Also, as physical properties of rocks such as thermal conductivity and elastic moduli change rapidly at elevated temperatures, the Nernst coefficient can very well change rapidly. The Nernst effect of rocks is a field that certainly needs serious investigation.

The third hypothesis is streaming potential. By this hypothesis an electromotive force will be set up if a conducting fluid is forced through tubes under high pressure. The electromotive force will be proportional to the pressure difference and inversely proportional to the viscosity of the fluid. Jakosky maintains that flow into wells can very well set up hundreds of millivolts of electrical potential difference. As cracks and fractures in the rocks can be equivalent to wells, the self-potential observed here can be very well caused by streaming potentials.

On the other hand, Wyllie (1963) challenges the idea that streaming potentials are the cause of self-potentials observed around wells. He contends the observed self-potential values are too high to be caused by streaming. He proposes an electrochemical effect caused by fluid motion of dilute solutions of magnesium and calcium as the source of the observed self-potential. In our case, this can very well be as magnesium and calcium ions can go into solution from feldspars in the basalt.

As mentioned above, the dipole source is dipping 50° to 60°. This agrees well with Decker's (1974) analysis of ground deformation data, in which he proposed that the east rift is dipping at 45° to the south. This dipping rift theory favors the streaming potential hypothesis. Hot water from deep thermal sources can be considered to be traveling upward along cracks that are inclined 45°.

The self potential data narrowed down the areas of interest to two small areas on the rift zone, but unambiguous interpretation of the data is not possible. Four hypothesis can be advanced as possible interpretations.

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5. Microearthquake and Microseismic Surveys

Investigators: W. Suyenaga
R. Norris
A. S. Furumoto

Although it was planned to carry out microearthquake surveys during the first year, it was decided to postpone these surveys until the second year. The main reason for this decision was the delay in getting delivery on equipment and that funds were being used up at a higher rate than anticipated in running the other surveys.

The field work done during 1974 included ground noise surveys in Puna, Pahala and South Point during February, June and August and a microearthquake survey in Puna during a three week period in August and September. Also much time was spent building and testing the microearthquake system and developing methods of data analysis for both types of work. For the microseismic or ground noise survey, a simple system was devised. The instrument package consists of two geophones, an amplifier bank, and a TEAC R-70 cassette tape recorder which can record in FM mode or in direct analog form. The package is small enough to be housed in the backseat of a compact car. For data processing, many techniques were tried; such as digitizing the records followed by power spectrum analysis by computer; use of machine frequency analysis. These were unsatisfactory as sampling or frequency resolution was poor. The best results were obtained by sending the taped signals through narrow band filters and obtaining rectified, averaged power levels.

As of this writing, the August field data are not yet fully analyzed. Details of all the work will appear later, but general conclusions of the

February noise survey was that most of the noise in Puna could be explained as being surf generated. In other words, there was apparently no association of ground noise to suspected geothermal areas, as defined by previous electrical surveys. However, there was one anomalously high amplitude 8 Hz site near one of the electrical resistivity anomaly found by Keller. Thus it was decided to make a detailed study around it.

This was done during June along with preliminary studies near Pahala and South Point. The latter two areas were chosen on the basis of infrared anomalies found by Abbott. The study in Pahala revealed nothing significant. The South Point areas showed a slight increase of ground noise toward the Kahuku Pali.

The results of the June Puna study are presently being combined with a more thorough field operation done in August. The latter survey included 59 stations taken during a five period when the microearthquake system was in operation. The continuous record of one or more of the MEQ sites should enable us to accurately account for any long term trends in the noise.

Preliminary results of the microearthquake survey reveal approximately 20 events recorded during September 1 to 9. However, more events should be found as playback techniques improve. Appropriate test parameters and crustal models are presently being chosen for HYPO71, the hypocenter location program developed by members of the U.S. Geological Survey.

Early results show that epicenters of some of the events are located on the rift zone near the Pahoa anomaly. The depth of any one event has a range of values, but the range of depths extend from 3 km to 15 km from ground surface.

6. Gravity Survey

Investigator: D. Klein

Fig. 10 shows the generalized Bouguer gravity-anomaly map of the island of Hawaii (Kinoshita, Pac. Sci., 19, p. 340). Of significance with regard to the geothermal exploration is the gravity expression of the East Rift of Kilauea which is the one area on Hawaii that has a promising electric resistivity low. Generally, the Bouguer anomaly is interpreted as an expression of a linear high density mass associated with rift intrusives. To a first approximation, normal to the rift alignment, the anomaly is about 10 to 20 mgal at its peak and has a half-wavelength of about 10 kilometers. From Fig. 10 it can be inferred that the axis of the anomaly is displaced slightly north of the present topographic expression of the rift. It is conjectural, but conceivable that the rift intrusive locus might have a slight northward dip. Equally conceivable is the possibility that the main intrusive feeders to the rift lie to the north of the most recent eruptive vents which might migrate rather randomly to one side or the other of the feeders at different episodes of extrusion.

With regard to the location of the heat sources which might be the cause for the electric resistivity low of Puna, it seems important to attempt to establish if the rift does dip and if so, how? For instance, if the self-potential anomalies found by C. Zablocki are expressions of abnormal sea level temperatures, these high temperatures could be fed by hydrothermal waters escaping from a deeper source along the rift fracture. For a dipping rift, the main heat source would not be directly below the anomaly.

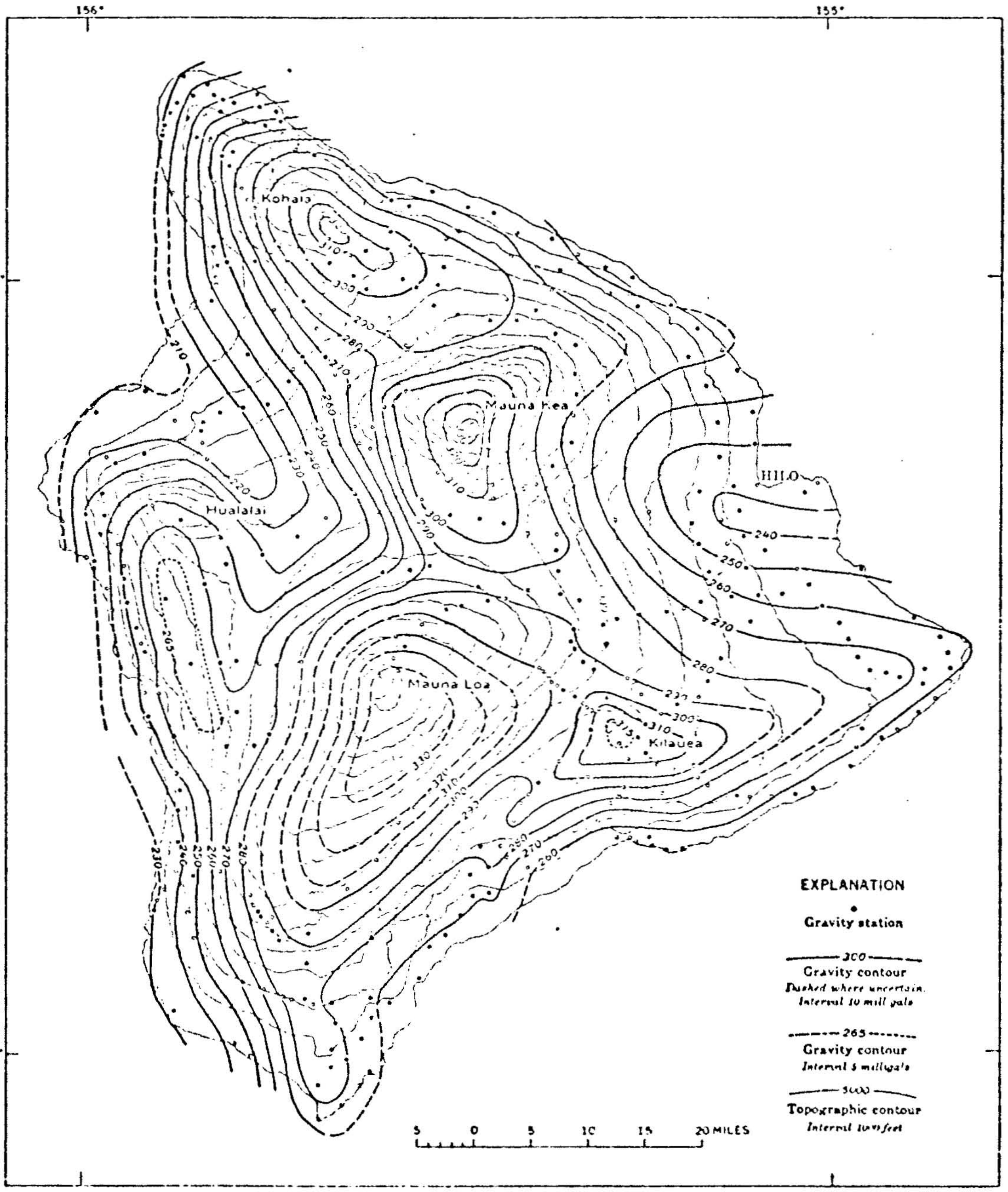

Figure 10. Bouguer Gravity Map of Hawaii Island
(from Kinoshita, 1965)

If the rift zone were distinguished by anomalously dense intrusives it is possible that its structure could be determined by a closely spaced gravity survey normal to the rift alignment.

With this in mind a traverse of closely spaced gravity stations was established along a 13,000 foot traverse roughly normal to the rift. The immediate purpose was to see if the near surface rift had a gravimetric signature. If it did, the next goal would be to model the structure of the rift.

Figure 11 shows the gravimetric Bouguer profile, projected along a line normal to the rift. The data was reduced using a mean rock density of 2.3 gm/cc. Terrain corrections have not been applied. Figure 12 shows a map of the survey stations. The line through the data is a 3rd degree polynomial curve, fit to remove the "regional". (Note the general trend of a 15 mgal regional with a high apparently to the north of the rift which follows Kinoshita's results.) Although the traverse is probably too short to adequately remove a "regional" trend by a polynomial, such a procedure does seem to indicate a possible residual high in gravity centered over the rift. The residual high looks symmetric and about 1 mgal in amplitude (see Fig. 11 top).

Although this preliminary analysis does not allow firm conclusions, there is a favorable possibility that the rift has a distinct gravimetric expression on fine scale. In the location of the present survey it would seem a model of a vertical rift is adequate. Based on these results it would be worthwhile to investigate the rift over at least one other location and extend the traverse both of this line and the next for a more adequate model of the deep rift expression.

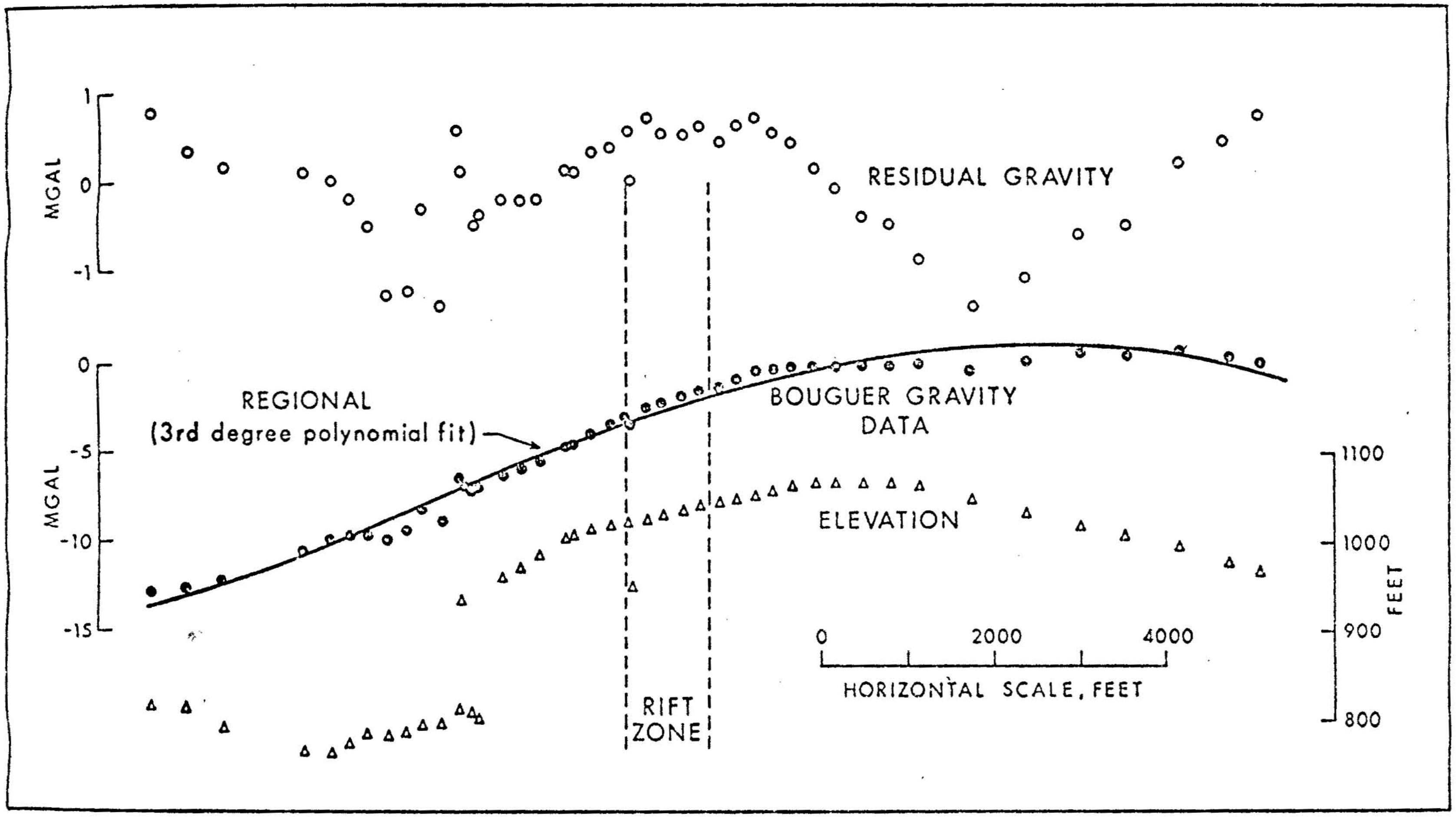

Figure 11. Station Elevations, Bouguer Gravity Values with Regional Trend and Residual Gravity (Bouguer data minus regional)

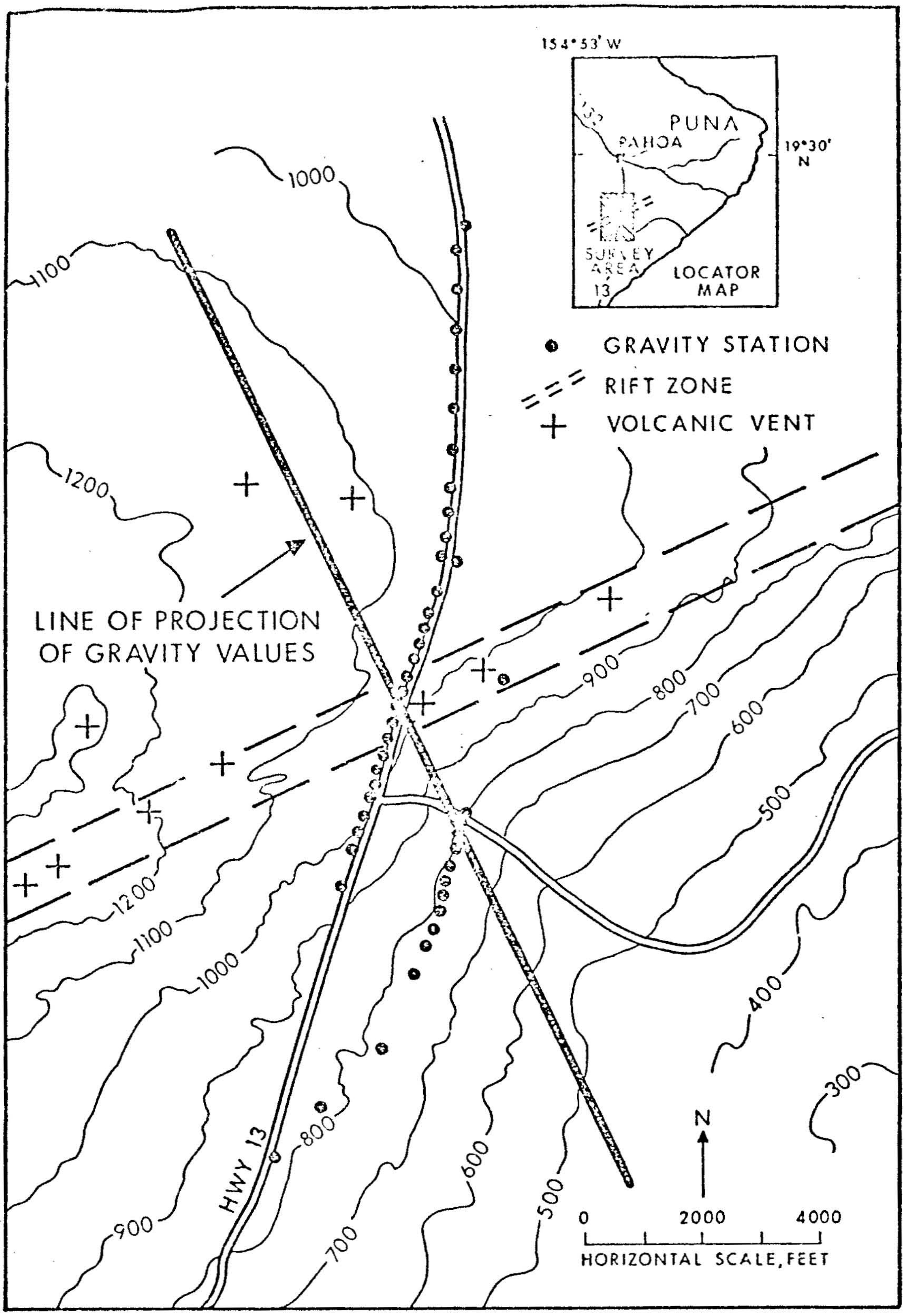

Figure 12. Survey Area and Gravity Stations

7. We . Temperature Survey

Investigators: J. Halunen
D. Epp

During the past few months we measured the variation of temperature with depth in a number of wells on Hawaii. The wells which have the highest temperatures are located on or near the East Rift of Kilauea in the Puna district. The location of the wells and the rift zones is shown in Fig. 13. Figure 14 is a plot of temperature versus elevation above mean sea level for these wells. The highest temperatures were recorded in "Geothermal test" wells 2 and 3. Those wells were drilled in 1961 by the Hawaii Thermal Power Company (Stearns, 1966). The elevation of the ground surface at Geothermal 2 is about 315 m, and the well does not penetrate to the water table. Since drilling, the hole has caved in at a depth of about 110 m, 60 m above the original bottom. Below 75 m the temperature increases with depth, and at 110 m reaches 97°C. The temperature at the bottom of the hole at the time of drilling was 102°C, and this suggests that the temperature probably continues to increase below the lowest depth we were able to reach. How much the temperature increases below 110 m cannot be ascertained with the present temperature data. The temperatures measured by Keller (1974) in the exploratory hole drilled just south of Kilauea increases to a local maximum ($\sim$ 85°C) just below the water table ($\sim$ 500 m depth), and increases again from $\sim$ 1000 m to the bottom of the hole. It cannot be determined whether the temperature increase observed at Geothermal No. 2 correlates with the upper or lower temperature increase observed in the hole south of Kilauea.

The other wells shown in the figures penetrate the water table. An increase in temperature at the water table is characteristic of these wells and is most pronounced at Geothermal test well number 3. This well, and to a lesser extent well number 9-9 also decreases in temperature near the bottom of the hole. Because these wells are located close to the coast, the fresh water lens is thin. It appears that the high temperatures observed are confined to this lens, thus lending support to the hypothesis that in this area groundwater has passed through a high temperature region as it flows seaward. The high temperatures observed may, therefore, be related to a heat source upslope from these wells.

Fig. 13 also shows the location of two wells (9-4 and 9-10) that are several miles from the rift zone. The temperatures in these wells is less than 27°C at all depths. Temperatures in other wells in this area which are not near the rift zone are also low.

The temperature data presented here, together with Keller's (1974) data, suggest that exploratory drill holes should be located along the East Rift zone, perhaps somewhere between Kilauea and Geothermal No. 2.

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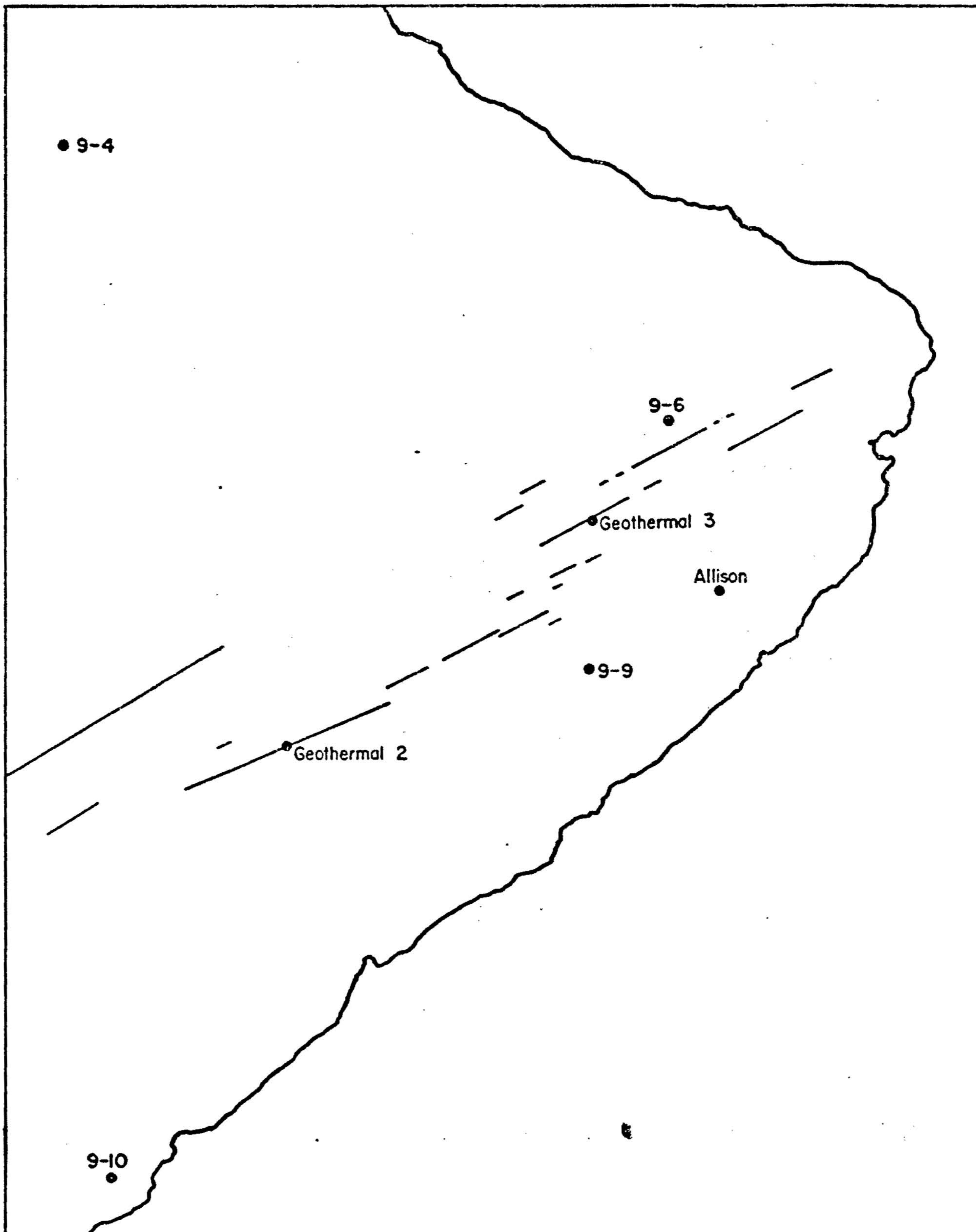
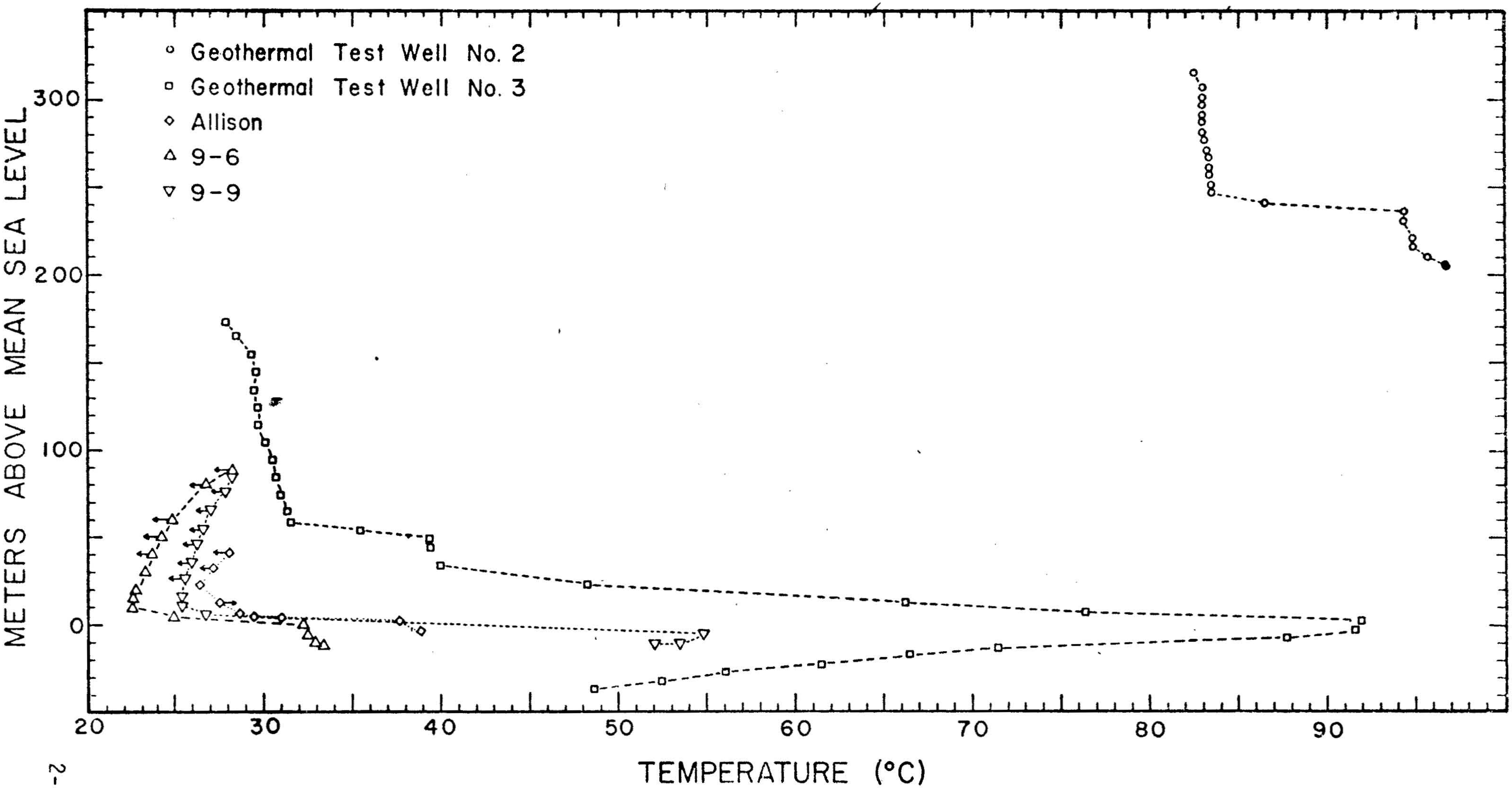


Figure 13. Location of Existing Wells in Puna Area

Figure 14. Temperature-Depth Profile of Wells



8. Resulting Publications

The present time is too early for the results of field surveys to see the light of publication. The infrared scanning survey is the only one of the field work that is in publishable form. However a study of published literature on the Koolau Volcano on the island of Oahu and on the Rabaul Volcano on the island of New Britain, Papua New Guinea, was done as a corollary to the project and papers on them were presented at the U.S.-Japan Cooperative Science Seminar held in Hilo, Hawaii, during the week of February 4-8, 1974. The papers were published recently in the Proceedings volume of the seminar. The authors and titles of the papers published are the following:

A. T. Abbott - Imagery from Infrared Scanning of the East and Southwest Rifts of Kilauea and the Lower Portion of the Southwest Rift of Mauna Loa, Island of Hawaii.Proceedings of the U.S.-Japan Science Seminar on Utilization of Volcano Energy. Sandia Laboratories 1974 pp. 10-12.

A. S. Furumoto - Geophysical Exploration on the Structure of Volcanoes: Two Case Histories, ibid, pp. 41-58.

W. A. Wiebenga and A. S. Furumoto - Geophysical Evidence for Availability of Geothermal Energy in New Britain, ibid., pp. 59-73.

SECTION IV. OVERVIEW OF PROPOSED GEOPHYSICAL RESEARCH PROGRAM

A. Status of the Problem

The reconnaissance surveys carried out over the island of Hawaii have narrowed the areas of interest to two spots on the east rift of Kilauea Volcano, the Pahoa and Opihikao anomalies. However, the best intepretation of the data cannot result in recommending the depth to which a hole should be drilled to determine whether there exists a utilizable geothermal source or not. Let us put together briefly whatever inferences we can draw from the data we have.

Klein in Task 2.2 has drawn up a temperature-depth profile based on his surveys and has assigned a temperature of 180°C to the 850 m depth. This seems promising for a geothermal source. However, Klein has assumed for his calculations the lower limit of resistivity and a porosity of 10%. These are the extremes of optimistic values. A more reasonable value for porosity is 14%, a value observed by Moore (1965) for rocks extruded at a depth of 760 m below sea level, which corresponds to 930 m below ground level in our discussion. A porosity of 14% with resistivity of 5 ohm-m will give a temperature of 110°C at 850 m. A resistivity of 7 ohm-m will give a value of 80°C.

The extremes of optimistic values say that the water at 850 m depth is hot enough for a geothermal source. From the point of view of statistics such a convenient choice of parameters is not quite justified. Hence we must conclude that as far as electrical resistivity data show, the existence of a geothermal source is marginal.

Should the temperature at 850 m be less than 140°C, which is the likely case, the chances of having a continuously flowing geothermal well is small. Keller (1974) drilled a deep hole in the summit area of Kilauea and obtained a temperature of 135°C to 140°C at the bottom of the hole. No convective motion in the well bore was noticed and there was no flashing to steam. Also, even if the scheme proposed by Elder (1965) were put into effect, the chances of a continuously discharging geothermal well is not likely.

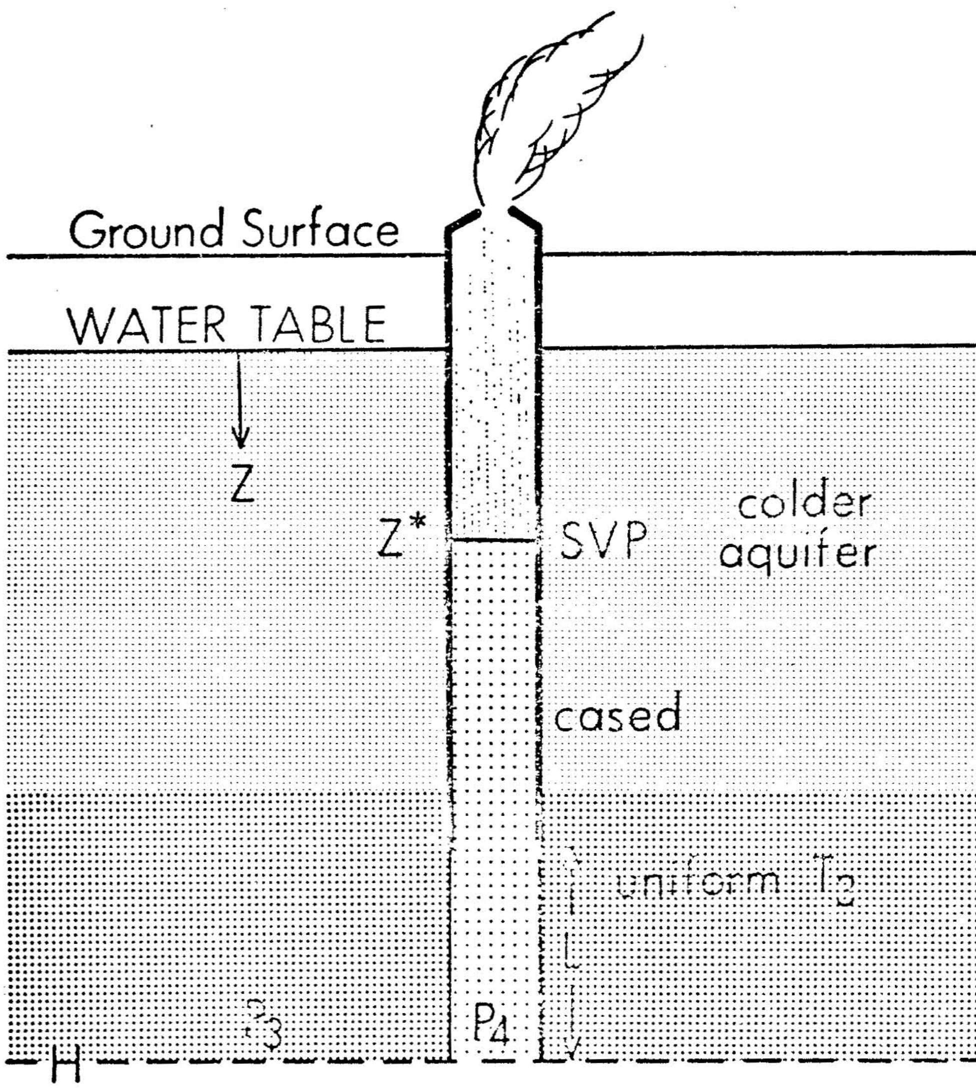
Let us consider Elder's scheme as shown in Figure 15. A well of depth H is drilled into a supposedly hot water aquifer of temperature T_3, and the well is only partly cased with a section L left uncased. The volume of water in the well bore is then disturbed by pumping compressed air into the bottom of the well. The pressure in the bottom of the well P_4 will be reduced, and there will be an upward surge of water up the well bore until point z* is reached where the hot water flashes into steam. At that time the pressure P_4 is

$$P_4 = SVP + \rho g\ (H-z^*),$$

where SVP is the saturated vapor pressure for temperature T_3 and ρ is the density of the water. The well will flow and flash continuously if P_3, the pressure in the aquifer, is greater than P_4. In practice, P_4 ends up being the hydrostatic pressure in the well.

In our case it is unlikely that P_3 will be greater than P_4. From seismic refraction data of Hill (1969) we know that P wave velocity at 600 m depth is 3.6 km/sec, which implies very competent rocks. With very little yielding, rock pressure will hardly contribute to aquifer pressure P_3. Elder's scheme works for sedimentary layers where yielding sediments contribute greatly to aquifer pressure.

However, our knowledge of pressure, temperature, and elastic moduli of rocks at depth are based on inferences from surface geophysical data and



A SELF MAINTAINING GEOTHERMAL WELL
ACCORDING TO ELDER

Figure 15

perhaps may not necessarily be the actual situation. For example, the rock at 850 m depth may be composed of clastics rather than solid basalt as Moore (1969) suggests. If so, porosity can be smaller and concomitantly the temperature can be higher. Also, clastics are much less competent than solid basalt, which in turn can mean that the scheme by Elder may be appropriate. These are just conjectures, but they indicate that there is still room for argument in challenging the foregoing interpretations. Further investigations are needed to determine whether the derived interpretations are correct, or whether the conjectures have basis in data.

Self potential data suggest streaming through cracks, although one must keep in mind that other explanations, such as electrochemical reactions, are just as viable. For the sake of argument, let us assume that streaming occurs. Then we infer that streaming originates as leaks from pressurized chambers and that the leaking hot fluid then moves upward along the cracks. At the present time, electrical resistivity methods have not revealed discontinuities that can be construed as boundaries of such a chamber. Microearthquakes on the other hand show that in the Pahoa and Opihikao anomaly areas stress releases occur at depths greater than 3 km. Stress releases in a volcanic region mean thermal processes. The seismic data may very well explain the failure of electrical methods to detect hot chambers or pressurized chambers, as the estimated limit of the depth of penetration for electrical methods used is 1.2 km.

Again, Keller's survey showed that a tongue of higher resistivity material covered the self-potential anomaly of Pahoa. If we proceed according to our customary interpretative method, we conclude that a layer of cooler subsurface water extends over the self-potential anomaly. This may mean that the volume of streaming water is so small that the surrounding ground water is not heated up. Or it can mean that the self-potential anomaly has an electrochemical origin rather than a streaming origin.

Another point to remember is that streaming potentials are usually observed in wells by letting one electrode into the well while the other is kept at ground surface. In our case, the potentials were observed by electrodes at the ground surface, 170 m above the water table. Zohdi and his colleagues (1973) did measure a self-potential anomaly over thermal areas in Yellowstone National Park and attributed the anomaly to streaming, but the values amounted to only 50 mV.

Analysis of oxygen isotope in water samples from existing wells in the Puna area at first gave a ray of hope for geothermal sources because the isotope ratio indicated that some water samples could have come from a region of elevated temperature of about 146°C. Subsequent reevaluation of various factors suggested the possibility of contamination or evaporation to give the observed values. These points should be carefully examined before coming to definitive conclusions.

In summary then, although interpretations from resistivity surveys do not give an encouraging picture, there is a possibility that the interpretations could be different because we do not know for certain porosity and resistivity of rocks and salinity of ground water at depth. Neither can we come to a definite conclusion on the nature of the self-potential anomaly. Oxygen isotope data at present can be considered ambiguous. Microearthquake data suggest that thermal processes are located at depths greater than 3 km.

B. The Proposed Geophysical Program

To tackle the problem as summarized in the previous discussion, the following objectives are proposed for the 1975 geophysical program:

1. Process the voluminous data gathered in 1973 and 1974, and refine the techniques of interpretation.

2. Determine in the laboratory physical properties of rocks, such as electrical conductivity, thermal conductivity, elastic moduli, under equivalent pressures and temperatures as at various depths.

3. Initiate chemical studies to know more about electrochemical sources that can produce self-potential anomalies.

4. Carry out limited field work to fill in gaps.

5. Carry out a drilling program to find out conditions at depth and to check out whether our geophysical interpretations are correct.

The first objective involves all the tasks that are in operation: geoelectric surveys, thermal well surveys, microseismic surveys, and geochemical surveys. Data collected by these tasks must be processed in a refined manner before they are ready for publication. The data that were discussed in this proposal are actually "first cut" data, data that were hastily processed to see whether they were consistent and to obtain a rough first view picture of the situation. Hence, they are not in appropriate form for public dissemination through journals or reports. It is expected that at least the first six months of 1975 will be required to process and interpret the data, before manuscripts for a definitive report are begun. Reports carrying partially completed analysis will be published from time to time, however.

In addition to the kind of surveys mentioned, gravity surveys and surface magnetic surveys were also carried out. Data from these will also be processed.

The second objective requires a new task, 2.8 Physical Properties of Rocks. The task leader, Dr. Murli Manghnani, is a leading authority on elastic properties of rocks under high pressure and temperature and has numerous publications to his credit. Using the sophisticated equipment available in his laboratory, he will measure the electrical and elastic properties of rocks under simulated conditions. Also, he will measure the magnitude of Nernst effect in volcanic rocks.

As mentioned, the nature of the self-potential anomaly is puzzling. Even when a hole is drilled into the anomaly, the answer may elude us. To ascertain whether electrochemical reactions could cause the anomaly, water samples from already existing wells and from the proposed exploratory drill hole will be analyzed chemically. As this is a rather tall order, a new task, 2.7 Hydrology, has been initiated. This task will also examine the hydrologic processes of the region to see whether electrokinetic processes could have caused the anomaly. This comprises the third objective of the program.

The fourth objective is to fill in gaps in the data. Task 2.2 Geoelectric Surveys will do more intense surveys around the anomalies. Task 2.5 Seismic Surveys will carry out seismic refraction-reflection surveys over the rift area near the anomalies. The scale of these surveys are to be small as we expect depth of penetration to 2 km.

The fifth objective, a drilling program, is large enough to warrant a section to itself.

C. The Drilling Program

A conclusion arrived at by the geophysical surveys is that the data are ambiguous until we can check them out by a drilling program. Hence, a drilling program is recommended as an exploratory project.

The drill hole should be over the Pahoa self-potential anomaly. It is recommended that the drilling go as deep as funds allow.

We expect to have some clues, if not answers, to the following questions:

(1) What is the nature of the self-potential anomaly at the depth of 170 m below surface? Is it electrochemical or electrokinetic?

(2) What is the nature of the rock at 800 m depth? Is it competent lava flows or is it clastic as Moore (1969) suggests?

(3) What are the elastic parameters and porosity of the rocks at about the water table, at 800 m depth and at 1200 m depth?

(4) What is the salinity of the ground water at various depths? What is the chemical composition of the groundwater at various places?

(5) What is the variation of temperature with depth?

A drill hole at the recommended spot should give the answer to whether geothermal resources are associated with Hawaiian volcanoes. If the answer is affirmative, we then use the drill hole data to recommend the likeliest spot where a production hole should be drilled.

In addition, a deep hole will provide abundant information on the volcano and volcanic processes. Especially, do we hope that clues will be provided so that we can figure out the mechanism of transfer of energy from the magma to the nearby hydrothermal system.

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SECTION V. INDIVIDUAL TASKS

Task 2.0

General Operations Support and Coordination

Investigator: A. S. Furumoto

The purposes of this task have been twofold: (a) to provide general services to the other geophysical tasks and (b) to plan the chronological sequence of field work of the different types of surveys so that one type of survey will be logically followed by the next with relevant data passed on.

To provide general services, there is a technician who has the responsibility of assembling and testing instruments and later on maintaining them. There is also an administrative assistant who doubles as a stenographer to handle typing of manuscripts, the processing of purchase orders and keeping the accounts of each task. The staff of this task has heavy responsibilities.

The geophysical program needs careful coordination, as the tasks are interrelated and aimed toward a goal. From time to time, a conference of all persons involved in the program, including student help, is held to assess the situation. In data processing and interpretation, such conferences will have to be held more frequently, as the interpretation process must consider all available data to obtain a whole picture of the situation. At times, when seemingly contradictory data are provided by different surveys, an interpretive model must be sought to account for the sets of conflicting data. So far, we have been successful in doing so.

Task 2.2

Geoelectric Surveys

Investigator: D. Klein

As the culmination of the geoelectric surveys, this task proposal is primarily for additional analysis of the data in hand with a minimum of field work to survey the resistivity in the intermediate depth range (sea level to 600 m) over the known self-potential and resistivity anomalies of Puna.

The exploration results to date indicate two outstanding geoelectric anomalies within the general resistivity low of the northeast Puna District. There are favorable indications that these anomalies are associated with geothermal heat.

If a sound geophysical model of these anomalies is to be presented for the purpose of proposing drilling, it is imperative that we close gaps and clear ambiguities in the present data.

To this end, a large part of the remaining work is to fully analyze and interpret the data in hand. The computer expenses and student help items in the budget are for this purpose. Further expenses are also proposed for additional soundings and profiles over the anomalies where the present data are inadequate. The field program is small, we propose about 30 days work; however, because of the nature of field work this is a large part share of the budget. The field work will be carried out in two or three phases as necessary in conjunction with detailed analysis of the data. This will allow maximum use of the developing model to plan observations.

One of our immediate goals in the field program is to make intermediate depth soundings over the known anomalies. This will provide resistivity information in the critical area (sea level to about 500 m) where our present data has an obvious gap and help in our understanding of the temperature gradient in this zone. One primary remaining question is whether or not there exist localized areas where the temperatures approach the boiling point. Although the temperature gradient on the average in the Puna area is abnormal, our present knowledge is insufficient to predict (or disclaim) that it reaches commercial geothermal temperatures.

Task 2.3

Computational Geophysics, Magnetic and Gravity Surveys

Investigators: A. S. Furumoto and R. A. Norris

The purpose of this task is to bring together the results of other tasks into a coherent model that can account for all the data gathered. In addition, some computer work is done for tasks that may need assistance. Also, gravity and magnetic surveys will be done by this task.

For the first three months, the task will be doing computer work to assist other tasks. One task is the processing of data from ground noise survey from Task 2.5. A system of processing using analog computers was set up so that power level in narrow bands around 1, 2, 4, 8, and 16 Hz could be determined automatically. Diurnal and seasonal variations of power level are also being taken into account.

A computer model of heat transfer by thermal conductivity is also being studied. This seeks answers to the deeper parts of a volcanic island, to see how much a volcanic source distorts the natural thermal gradient of the earth. This helps in determining sizes of geothermal sources, if such exist.

In January 1975, the task will carry out gravity surveys over Puna with a dense net of observations. Two traverses perpendicular across the east rift are being planned. These are needed to estimate where the magma chambers are. At present, they seem to be north of the rift, and seem to conflict with the deformation analysis of Decker (1974).

The task will install tide gauges in a few existing wells near the seashore and at two places in the seashore. From phase lags of tides in wells, we intend to compute the permeability of rocks between the seashore and wells. The theory is being worked out.

The task will devote the second half of 1975 to pulling together the results of all the tasks to derive a model of the hydrothermal system of the east rift that will be consistent with all the data gathered.

Task 2.4

Temperature Survey

Investigators: D. Epp and J. Halunen

During the past field season we measured the temperature vs. depth profile in 21 wells in the Puna and South Point areas and along the Kona coast. Some of the wells we had originally hoped to measure are now blocked or otherwise inaccessible. A number are being pumped, which results in an isothermal temperature gradient in the hole. There are some wells in these areas that we have not yet been able to locate, and, in addition, there a number of wells along the north coast of the island which we have not yet measured. We plan to measure these wells this year or early in 1975.

Also, in the next year we will choose several wells in the Puna area, and perhaps one or two other wells, for repeated temperature measurements. We will measure the temperature variation with depth as often as practical during 1975. This temperature data will provide information on rates and directions of groundwater movement, and possibly changes in heat source areas, and, in addition, will support the geochemical work that is being proposed.

Groundwater movement through the area around a well will upset the normal temperature gradient due to the earth's heat (see, for example, Birch, 1947). Stallman (1963), Bradehoeff and Papadopulos (1965), Domenico and Palciauskas (1973), and others have shown that this deviation from the norm can be used to calculate the velocity of groundwater movement. Because of the high permeability of the islands and the low thermal conductivity of rock, groundwater movement is probably the dominant process that moves heat from the areas within the island that contain hot magma. If the hydrological system in the island is largely an open system as proposed by Mink (1964), the heat from hot magma sources will be carried to the ocean by moving groundwater. On the other hand, if closed systems exist within the island, the hot magma source will cause convection of the groundwater within the system. The proposed temperature surveys should allow us to determine which of these two systems exist at shallow depths in the Puna area, and, in addition, the velocity of groundwater movement within the system.

References

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Bredehoeff, J. D., and I. S. Papadopulos, Rates of groundwater movement estimated from the earth's thermal profile, Water Resources Res., 1, 325-328, 1965.

Domenico, P. A., and V. V. Palciauskas, Theoretical analysis of forced convective heat transfer in regional groundwater flow, Geol. Soc. Am. Bull., 84, 3803-3814, 1973.

Mink, J. F., Groundwater temperature velocity in a tropical island environment, J. Geophys. Res., 69, 5225-5230, 1964.

Stallman, R. W., Computation of groundwater velocity from temperature data, U.S. Geol. Survey Water-Supply Paper 1544-H, 36-46, 1963.

Task 2.5

Seismic Studies

Investigators: W. Suyenaga and A. S. Furumoto

The seismic studies will consist of the following:

1. Seismicity study of microearthquakes including the use of borehole seismometers
2. Processing and analysis of seismic data obtained during June-September 1974.
3. Refraction and reflection probes of the fault zone

1. Microearthquakes will be continued to be monitored in the Puna area during the calendar year. Seasonal variation of earthquakes has been observed in other seismic areas, and perhaps Puna area may also show such variation. However, if microearthquakes are associated with geothermal sources, there should be a level of seismicity irrespective of seasons.

2. During June to August 1974, a large amount of data on seismic noise survey and microearthquake monitoring has been gathered. The main part of this task will be data processing and interpretation.

For the microearthquake monitoring, a computer program to locate epicenters is being prepared. The program is a slight modification of HYPO71 which was developed by staff members of the U.S. Geological Survey.

3. It has been suggested by Decker (1974) on the basis of deformation studies that the fault zone of the East Rift dips approximately 45° to the southeast. Seismicity studies (Koyanagi _et al_., 1972) show that earthquake activity is limited to the area south of the rift zone. This suggests a similar dipping fault zone. Also, as presented elsewhere in this proposal, one

interpretation of the shape of the Pohoiki self-potential includes a dipole dipping at 45° to the southeast.

It is, therefore, proposed that seismic reflection and refraction be used to probe this feature. Massive dikes would probably provide a sufficient density contrast to reflect measurable seismic energy, if the intrusive system is thick enough. The seismic refraction and reflection surveys will use explosives; but only small amounts, up to 2 lbs. charges, are sufficient as we expect to probe to a maximum depth of 2 km. As the Hawaii Institute of Geophysics has been doing refraction-reflection surveys since 1963, a lot of the equipment is available.

References

Decker, R. H., and J. Dietrich (1974). Limitations of Elasticity Theory in Interpretation of Ground Surface Deformation. Paper presented at U.S.-Japan Seminar on Utilization of Volcano Energy, Hilo, Hawaii, Feb. 1974.

Koyonagi, R. Y., D. A. Swanson and E. T. Endo (1972). Distribution of Earthquakes Related to Mobility of the South Flank of Kilauea Volcano, Hawaii, U.S. Geological Survey Prof. Paper 800-D, pp. D89-D97.

Task 2.6

Geochemical Surveys

Investigator: Pow-foong Fan

Studies of the stable isotopes of oxygen and hydrogen in groundwater have been found to be useful in the discovery and evaluation of geothermal systems. In addition, studies of sodium, potassium and calcium concentrations in the groundwater have recently been shown to be another useful geochemical tool in investigating geothermal systems (Coplen, 1973; Fournier and Truesdell, 1973).

Oxygen and deuterium isotope studies of 10 wells and 2 warm-water springs have been made in the Puna Rift System of Kilauea Volcano, island of Hawaii. Temperature and chemical measurements have also been analyzed in an effort to determine the thermal history of the groundwater. Results show a positive correlation between δO^{18} and temperature, especially where the Puna waters are compared with other Hawaiian waters. The O^{18} enrichment can be interpreted as water-rock exchange at geothermal temperatures (> 150°C) or contamination of fresh waters by seawater advection since the Puna waters showing the greatest enrichment also have high salinity. Both processes probably occur there and either can result from thermal anomalies at depth.

We propose (1) to make a detailed literature study of the geochemistry of the Hawaiian Islands, especially the geochemistry of Kilauea Volcano; (2) to make chemical and isotopic studies of the groundwater; and (3) to determine mineralogical and chemical compositional changes that may have resulted from hydrothermal alteration processes.

We plan to sample water from wells, springs, local precipitation, and geochemical fluids in the Puna, Great Crack and South Point regions of the island of Hawaii. Special effects will concentrate on study of water and rock samples from the proposed 8 shallow holes from Puna target areas. We hope our data will assist the site selection of the deep holes that will eventually be drilled on the island of Hawaii.

The alteration products, hematite, amorphous iron, opal and kaoline, were formed by reactions of gases and wall-rock at Sulphur Bank, near the Volcano House on the north rim of Kilauea Caldera. Similar deposits are present in areas along the southeastern boundary cliff of Kilauea Caldera and the Southwest Rift Zone of Mauna Loa near Sulphur Cone. Hydrothermal alteration products that are characterized by chlorite-quartz assemblages are found in the Iao Valley of West Maui and Keolu Hills of windward Oahu. Zeolites and calcite are present 4,000 feet at depth of Keller's well at Kilauea. The mineral assemblages of hydrothermal alteration vary from place to place. More detailed mineralogical and chemical studies are needed to understand the influences of the gas-liquid-solid interface reaction between hydrothermal fluid, groundwater, and wall-rock. Opal, quartz, calcite, kaoline and other minerals resulted from hydrothermal alteration would be deposited in the pores of the rocks and possibly form a impermeable dome around the self-sealing steam reservoir. The identification and understanding of different types of Hawaiian hydrothermal alteration products would be useful background information prior to the drilling project.

Task 2.7

Hydrology

Investigators: R. W. Buddemeier, P. M. Kroopnick,
L. S. Lau

Hydrology and hydrogeochemistry are the disciplines which most extensively overlap and integrate all areas of geothermal energy exploration and exploitation. The following non-inclusive list illustrates some of the major concerns which require a systematic approach to the hydrology of geothermal areas:

(1) Many of the most promising exploratory techniques are mediated or controlled by the hydrologic and/or hydrogeochemical characteristics of the system. Specifically, (a) heat flow and temperature measurements (see Task 2.4) must be interpreted in terms of flowing groundwater as a heat-transport medium, and can in turn yield hydrologic information if coupled with an adequate model or other information; (b) self-potential and electrical resistivity anomalies may depend on groundwater streaming potentials or oxidation-reduction reactions in a vertically unstable water column, both of which require knowledge of flow rates, patterns, and the chemical composition of the groundwater for interpretation (see Task 2.2); and (c) isotopic and chemical water analyses (Task 2.6) provide clues as to the thermal history of groundwater and the characteristics of the thermal reservoir, but are of marginal utility unless they can be combined with some knowledge of advection patterns, dilution effects and re-equilibration with non-thermal aquifer material.

(2) The geochemical and geophysical characteristics of a geothermal reservoir, and in particular the rates and mechanisms of recharge by

intrusive saline water and/or meteoric waters, will determine both the nature of the resource (brine, hot water, steam) and its exploitability in terms of sustainable yield, and are important inputs to any modeling or predictive effort (Tasks 2.3 and 3.1).

(3) The chemical and physical characteristics of the geothermal fluids, and their variations with time, are critical to the design of energy extraction equipment and processes (Task 3.6).

(4) Exploratory drilling and ultimate exploitation, including fluid extraction or injection, brine disposal, etc., must be conducted with regard for the agricultural and potable water resources of the region, the possible effect on volcanic or seismic activity patterns of the region, and the long-term stability of the resource itself, all of which require extensive knowledge of the regional hydrology.

This task proposal is to develop a systematic approach to describing and eventually modeling the hydrology and hydrochemistry of the most promising geothermal areas. Most of the attention will be devoted to the Puna District in anticipation of test drilling there; however, the situations at South Point and other potential areas will be reviewed to see if some exploratory field work is justified.

The effort will include assessment of the information requirements of tasks which will utilize hydrologic information, coordination with the tasks (cited above) which already propose to produce hydrologically relevant data, and field sampling and analysis to provide necessary data not being produced under other tasks. The major thrusts of the proposed work are summarized below:

(1) Collection and evaluation of regional hydrologic data, including rainfall, head and tidal response data from existing wells, ^{2}H, ^{3}H and ^{18}O

data on rainfall and groundwater. The stable isotopes are a valuable tool for recharge source identification (1) and recognition of geothermal equilibration effects (2,3,4,5) while tritium studies can provide water residence time and circulation rate data. These methods have been demonstrated both in geothermal areas (6) and in other Hawaiian groundwater studies (7,8,9).

(2) Probing existing wells to establish vertical profiles of salinity, pH, Eh (or an appropriate oxidation-reduction equivalent) and temperature, and variations in these profiles with time, tide and rainfall. To date, only temperature probing has been proposed or accomplished; chemical analyses have been limited to surface samples, which does not provide information relevant to vertical water stratification, convective overturn or upwelling, or identification of the characteristics of water more closely associated with the heat source and removed from the effects of atmospheric or soil-zone interactions.

(3) Collection of vertical profiles of samples, either by thief samplers or jet pumping, to provide data on the vertical structure of chemical and isotopic effects in the water. In addition to the isotopic methods mentioned above and the major element distributions thought to be relevant to geothermal alteration (1) (some of which have already been partially investigated under Task 2.6), it will be critical to seach for concentration gradients of identifiably volcanic or marine origin species, as well as the oxidation-reduction characteristics of the water. The hydrologic implications of these geochemical studies (5,11) will be carefully coordinated with Professor J. J. Naughton's ongoing research into volcanic gas (especially H_2/He) emissions in the Kilauea area.

(4) During and after the drilling of test holes in the Puna (or other geothermal)District, samples of opportunity will be taken and the test wells

will be probed and studied intensively in comparison with the existing water wells in the area.

(5) The data will be assembled and interpreted to produce a general hydrologic picture of the region of interest, specific descriptions or models of the geothermal reservoirs and the hydrologic regimes in their immediate environs, and to relate the results of geochemical and geophysical prospecting observations to specific subsurface hydrogeochemical conditions.

Pumping tests on the test wells are considered an important aspect of test drilling; sampling the pumped fluid as a function of time and total withdrawal can provide isotopic and chemical data on the size and potential yield of the reservoir, if one exists, and concurrent head observations on other wells will provide information on area hydrology and interconnections. Funds for this are not budgeted under this present task, however, as it is felt that this should either be included in the drilling budget or in the Hydrology task budget for the next project year, when the results of this study will provide a better basis for experimental design.

References

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(5) Mazor, E. and B. Th. Verhagen (1974). Hot Springs of the Igneous Terrain of Swaziland: Their Noble Gases, Hydrogen, Oxygen and Carbon Isotopes and Dissolved Ions. Proc. Symp. Isotope Techniques in Ground-Water Hydrology, IAEA, Vienna (in press).

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(9) Hufen, T. H., R. W. Buddemeier and L. S. Lau (1974b). Radiocarbon, Carbon-13 and Tritium in Water Samples from Basaltic Aquifers and Carbonate Aquifers on the Island of Oahu, Hawaii. Proc. Symp. Isotope Techniques in Ground-Water Hydrology, IAEA, Vienna (in press).

(10) Fournier, R. D. and A. H. Truedell (1973). An Empirical Na-K-Ca Geothermometer for Natural Waters. Geochim. Cosmochim. Acta 37, 1255-1276.

(11) Buddemeier, R. W. and A. Puccetti (1974). C-14 Dilution Estimates of Volcanic CO_2 Emission Rates (abstr.). E.O.S. Trans. Am. Geophys. Union 55(4), p. 488.

Task 2.8

Physical Properties of Rocks

Investigator: M. H. Manghnani

In geophysical exploration for potential geothermal energy in Hawaii, seismic, heat flow, and electric methods have been found to provide most of the direct and indirect knowledge about the subsurface parameters such as rock porosity, temperature, pore fluid and salinity.

We propose here laboratory studies involving seismic, thermal and electrical properties of Hawaiian basaltic rocks selected from potential geothermal areas.

Seismic velocity in a rock depends upon density, porosity, composition (or, mean atomic weight), pressure and temperature at depth. As the effects of temperature and fluid content on velocity in vesicular basalts at modest pressures (1-5 kbar) have not been fully studied, a realistic interpretation of the subsurface temperature distribution, a useful indicator of successful exploitation of geothermal energy, cannot be made from the observed seismic data. One of the objectives of the proposed work will be to investigate the effects of temperature, modest pressure, and fluid content on velocity in selected basalts from the Island of Hawaii.

Recently, it has been shown that both V_p and V_s in rock and rock-forming minerals having the same mean atomic weight are linearly related to thermal conductivity.[1,2,3] Such a relation, if established for the Hawaiian basaltic rocks, would be most useful for interpretation, from seismic velocities, subsurface thermal conductivity and hence the temperature distribution beneath

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(See footnotes at the end of this task description.)

the potential areas. A knowledge of thermal conductivity of basalts as a function of density, porosity, fluid content, and temperature is also needed for the interpretation of heat flow measurements.

That the velocity is also in some manner related to the electrical resistivity of rocks was recently noted.[4] Besides this, there is a real need to know the effect of porosity, fluid content of variable salinity, temperature, and modest pressure on the electrical resistivity of basaltic rocks in order to interpret the field electrical resistivity measurements.

It is believed now that volcanoes generate electric currents of very low amplitude during eruption. Such geothermal manifestations, believed to be associated with the Nernst effect[5,6] give rise to transient electric and magnetic anomalies. In addition to the research proposed above, we also propose that the qualitative and quantitative analysis of the Nernst effect in Hawaiian basaltic rocks be investigated in the laboratory and, if possible, in the field.

We propose here a threefold program:

1. To undertake laboratory studies to investigate the relationships among geophysical parameters, such a velocity (V_p and V_s), thermal conductivity, and electrical resistivity of basaltic rocks having various density, porosity and fluid content of variable salinity under pressure and temperature environments compatible with depth to a few kilometers of interest (i.e., to 300°C and to 2 kbar). The results will enable us to understand the effects of porosity, fluid content, and temperature on the important physical properties now being measured in the field and to establish any relationships among these parameters.

2. To use the laboratory results in the interpretation of observed geophysical data for locating the dense subsurface rock and the "optimum" heat source.
3. To conduct preliminary laboratory experiments to study the Nernst effect in Hawaiian basaltic rocks. This would involve a qualitative and quantitative evaluation of electric currents in selected Hawaiian basalts placed in magnetic and thermal gradient consistent with those existing at depths of several kilometers.

The subject basaltic rocks will be collected from the volcanic areas of geothermal importance. The pulse transmission method of V_p and V_s measurements[7] will be used. For studying the electrical resistivity of basaltic rocks under various temperature and pressure environments the technique described by Brace et al. (1965)[8] will be followed. For the thermal conductivity measurements, the line-source transient method,[9, 10] will be used. Most of the necessary equipment for carrying out the proposed laboratory measurements is available. However, some electronic equipment is needed for making the electric and thermal conductivity, as well as for investigating the Nernst effect.

Footnotes

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2. Horai, K. and A. Nur, Relationship among Terrestrial Heat Flow, Thermal Conductivity, and Geothermal Gradient, J. Geophys. Res., vol. 75, pp. 1985-1991, 1970.
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9. Jaeger, J.C., The Uses of Complete Temperature Time Curves for Determination of the Thermal Conductivity with Particular Reference to Rocks, Aust. Jour. Phys., vol. 12, 3, 203-217, 1959.

10. Jaeger, J.C. and J.H. Sass, A Line Source Method for Measuring the Thermal Conductivity and Diffusivity of Cylindrical Specimens of Rocks and the Other Poor Conductors, Brit. J. Appl. Phys., vol. 15, 1187, 1964.

General Services and Coordination

Task 2.0

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Augustine S. Furumoto

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. ______ (Co) Principal Investigator(s)			1	$ 2,186
b. ______ Faculty Associates				
Sub-Total				2,186
2. Other Personnel (Non-Faculty)				
a. ______ Research Associates—Postdoctoral				
b. ______ Non-Faculty Professionals				
c. ______ Graduate Students				
d. ______ Pre-Baccalaureate Students 900 hrs at $2.75				2,475
e. ______ Secretarial—Clerical 100%				9,960
f. ______ Technical, Shop, and Other 100%				10,800
TOTAL SALARIES AND WAGES				25,421
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				3,176
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				28,597
D. PERMANENT EQUIPMENT				
E. EXPENDABLE EQUIPMENT AND SUPPLIES				
F. TRAVEL 1. Domestic (Including Canada) (See below)*				600
2. Foreign				1,965
G. PUBLICATION COSTS				
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				850
I. OTHER DIRECT COSTS Trailer repair $400; Vehicle rental 600; Communication 300				1,300
J. TOTAL DIRECT COSTS (C through I)				33,312
K. INDIRECT COSTS 46.2% of $21,455 = $9,912; 34.13% of 3,966 = 1,354; $25,421				11,265
L. TOTAL COSTS (J plus K)				44,577
Residual Balance at 12/31/74				7,479
M. ~~AMOUNT OF THIS AWARD (ROUNDED)~~ Adjusted Request				$ 37,098

REMARKS: Use extra sheet if necessary

*Field work, airfare and per diem $1,265
Meeting, east coast 700

NSF FORM 569, JULY 1971 SUPERSEDES ALL PREVIOUS EDITIONS

Geoelectric Survey

Task 2.2

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Augustine S. Furumoto

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. ____ (Co) Principal Investigator(s)				$
b. 1 Faculty Associates	11			11,880*
Sub-Total				11,880*
2. Other Personnel (Non-Faculty)				
a. ____ Research Associates—Postdoctoral				
b. ____ Non-Faculty Professionals				
c. 1 Graduate Students				4,812
d. 2 Pre-Baccalaureate Students				2,250
e. ____ Secretarial—Clerical				
f. ____ Technical, Shop, and Other				1,500
TOTAL SALARIES AND WAGES				20,442
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				2,809
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				23,251
D. PERMANENT EQUIPMENT				
E. EXPENDABLE EQUIPMENT AND SUPPLIES				2,000
F. TRAVEL 1. Domestic (Including Canada) 8 interisland trips - $480; 1 mainland conference; 14 man days per diem for 2				1,960
2. Foreign				
G. PUBLICATION COSTS				1,500
H. COMPUTER COSTS IF CHARGED AS DIRECT COST 10 hrs @ $198/hr				1,980
I. OTHER DIRECT COSTS Communications - 150; M/R equipment - 1,000; Interisland freight - 400; Vehicle - 2,700; Gas - 300; Diesel - 90				4,640
J. TOTAL DIRECT COSTS (C through I)				
K. INDIRECT COSTS 46.2% of $17,272 = $7,980; 34.13% of 3,170 = 1,082; $20,442				9,062
L. TOTAL COSTS (J plus K)				44,393
Residual Balance at 12/31/74				12,080
M. ~~AMOUNT OF THIS REQUEST~~ Adjusted Request				$ 32,313

REMARKS: Use extra sheet if necessary

*Includes anticipated 10% salary increase

NSF FORM 569, JULY 1971 — SUPERSEDES ALL PREVIOUS EDITIONS

Computations, Gravity and Magnetic Surveys

Task 2.3

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Augustine S. Furumoto

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. ______ (Co) Principal Investigator(s)				$
b. ______ Faculty Associates				
Sub-Total				
2. Other Personnel (Non-Faculty)				
a. 1 Research Associates—Postdoctoral	12			12,900
b. ______ Non-Faculty Professionals				
c. ______ Graduate Students				
d. ______ Pre-Baccalaureate Students 500 hrs @ $2.75				1,375
e. ______ Secretarial—Clerical				
f. ______ Technical, Shop, and Other				
TOTAL SALARIES AND WAGES				14,275
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				1,953
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				16,228
D. PERMANENT EQUIPMENT 3 Tide gauges				450
E. EXPENDABLE EQUIPMENT AND SUPPLIES				1,000
F. TRAVEL 1. Domestic (Including Canada) Field work: airfare and per diem				1,800
2. Foreign IUGG Meeting, Grenoble, France				1,400
G. PUBLICATION COSTS				850
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				1,490
I. OTHER DIRECT COSTS Vehicle rental 30 days @ $30/day = $900 Communications $300				1,200
J. TOTAL DIRECT COSTS (C through I)				24,418
K. INDIRECT COSTS 46.2% of $12,376 = $5,718 34.13% of 1,899 = 648 $14,275				6,366
L. TOTAL COSTS (J plus K)				30,784
Residual Balance at 12/31/74				8,190
M. ~~AMOUNT OF THIS REQUEST~~ Adjusted Request				$ 22,594

REMARKS: Use extra sheet if necessary

NSF FORM 569, JULY 1971

SUPERSEDES ALL PREVIOUS EDITIONS

Thermal Survey

Task 2.4

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Augustine S. Furumoto

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. ____ (Co) Principal Investigator(s)				$
b. ____ Faculty Associates				
Sub-Total				
2. Other Personnel (Non-Faculty)				
a. ____ Research Associates—Postdoctoral				
b. ____ Non-Faculty Professionals				
c. 2 Graduate Students 4 mos. $3,716; 3 mos $3,183				6,899
d. ____ Pre-Baccalaureate Students				
e. ____ Secretarial—Clerical				
f. ____ Technical, Shop, and Other				
TOTAL SALARIES AND WAGES				6,899
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				897
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				7,796
D. PERMANENT EQUIPMENT				
E. EXPENDABLE EQUIPMENT AND SUPPLIES				4,112
F. TRAVEL 1. Domestic (Including Canada) Field work: airfare $442; per diem $1,800				2,242
2. Foreign				
G. PUBLICATION COSTS				
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				
I. OTHER DIRECT COSTS Car Rental $1,210				1,210
J. TOTAL DIRECT COSTS (C through I)				16,058
K. INDIRECT COSTS 46.2% of $4,070 = $1,880; 34.13% of 2,829 = 965; $6,894				2,845
L. TOTAL COSTS (J plus K)				18,903
Residual Balance at 12/31/74				8,262
M. ~~AMOUNT OF THIS AWARD (ROUNDED)~~ Adjusted Request				$ 10,641

REMARKS: Use extra sheet if necessary

Seismic Survey

Task 2.5

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Augustine S. Furumoto

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. ____ (Co) Principal Investigator(s)				$
b. ____ Faculty Associates				
Sub-Total				
2. Other Personnel (Non-Faculty)				
a. ____ Research Associates—Postdoctoral				
b. ____ Non-Faculty Professionals				
c. 2 Graduate Students				13,404
d. 2 Pre-Baccalaureate Students				2,200
e. ____ Secretarial—Clerical				
f. 1 Technical, Shop, and Other				2,000
TOTAL SALARIES AND WAGES				17,604
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				234
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				17,838
D. PERMANENT EQUIPMENT				0
E. EXPENDABLE EQUIPMENT AND SUPPLIES				2,000
F. TRAVEL 1. Domestic (Including Canada) Field work (airfare + per diem) plus AGU meeting				4,600
2. Foreign				
G. PUBLICATION COSTS				800
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				600
I. OTHER DIRECT COSTS Comm. $ 400; Equipm maint. 1,000; Vehicle rental 1,800				3,200
J. TOTAL DIRECT COSTS (C through I)				29,038
K. INDIRECT COSTS 46.2% of $13,404. = $6,193; 34.13% of 4,200 = 1,433; $17,604				7,626
L. TOTAL COSTS (J plus K)				36,664
Residual Balance at 12/31/74				11,200
M. ~~XXXXXXXXXXXXXXXXXXXXXXXX~~ Adjusted Request				$ 25,464

REMARKS: Use extra sheet if necessary

Geochemical Survey

Task 2.6

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Augustine S. Furumoto

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. ____ (Co) Principal Investigator(s)			1	$ 1,727
b. ____ Faculty Associates				
Sub-Total				1,727
2. Other Personnel (Non-Faculty)				
a. 1 Research Associates—Postdoctoral		9	3	6,345
b. ____ Non-Faculty Professionals				
c. ____ Graduate Students				
d. 2 Pre-Baccalaureate Students				3,500
e. ____ Secretarial—Clerical				
f. ____ Technical, Shop, and Other				
TOTAL SALARIES AND WAGES				11,572
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				154
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				11,726
D. PERMANENT EQUIPMENT				
E. EXPENDABLE EQUIPMENT AND SUPPLIES				2,800
F. TRAVEL 1. Domestic (Including Canada) Field work ($4,395) meeting ($750)				5,145
2. Foreign				
G. PUBLICATION COSTS				2,000
H. COMPUTER COSTS IF CHARGED AS DIRECT COST 1 hr.				298
I. OTHER DIRECT COSTS Communications $300; Maintenance, repair 300				600
J. TOTAL DIRECT COSTS (C through I)				22,569
K. INDIRECT COSTS 46.2% of $11,572 = $5,346				5,346
L. TOTAL COSTS (J plus K)				27,915
Residual Balance at 12/31/74				10,843
M. ~~XXXXXXXXXXXXXXXXXXXXXXXX~~ Adjusted Request				$ 17,072

REMARKS: Use extra sheet if necessary

NSF FORM 565, JULY 1971

SUPERSEDES ALL PREVIOUS EDITIONS

Hydrology

Task 2.7

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Augustine S. Furumoto

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. ______ (Co) Principal Investigator(s)				$ 1,670
b. ______ Faculty Associates				
Sub-Total				1,670
2. Other Personnel (Non-Faculty)				
a. ______ Research Associates—Postdoctoral				
b. ______ Non-Faculty Professionals				
c. 2 Graduate Students				11,170
d. ______ Pre-Baccalaureate Students				1,000
e. ______ Secretarial—Clerical				
f. ______ Technical, Shop, and Other				
TOTAL SALARIES AND WAGES				13,840
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				183
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				14,023
D. PERMANENT EQUIPMENT				3,500
E. EXPENDABLE EQUIPMENT AND SUPPLIES				2,500
F. TRAVEL 1. Domestic (Including Canada)				3,500
2. Foreign				
G. PUBLICATION COSTS				400
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				450
I. OTHER DIRECT COSTS: Consultant $1,000; Sample analysis 200				1,200
J. TOTAL DIRECT COSTS (C through I)				25,573
K. INDIRECT COSTS: 46.2% of $12,950 = $5,983; 34.13% of 890 = 304; $13,840				6,287
L. TOTAL COSTS (J plus K)				31,860
Residual Balance at 12/31/74				11,550
M. ~~XXXXXXXXXXXXXXXXXXXXXXXX~~ Adjusted Request				$ 20,310

D. PERMANENT EQUIPMENT:

Heater Control and Pyrometer for Deuterium System	$112
Portable pH Meter	660
Vacuum/air Regulator	213
Portable Dissolved Oxygen Meter	450
Sensor with 250 feet of wire	740
Specific in electrodes H5818-16	175
" " H5817-17	150
Mass Spectrometer Component Valve for D/H System (4@$150)	600
Down Hole Water Sampler (2@$200)	400
TOTAL	$3,500

NSF FORM 569, JULY 1971 SUPERSEDES ALL PREVIOUS EDITIONS

Physical Properties of Rocks

Task 2.8

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Augustine S. Furumoto

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. ___ (Co) Principal Investigator(s)				$
b. 2 Faculty Associates	5		1	6,900
Sub-Total				6,900
2. Other Personnel (Non-Faculty)				
a. ___ Research Associates—Postdoctoral				
b. ___ Non-Faculty Professionals				
c. 1 Graduate Students				5,485
d. ___ Pre-Baccalaureate Students				
e. ___ Secretarial—Clerical				
f. ___ Technical, Shop, and Other				
TOTAL SALARIES AND WAGES				12,385
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				1,377
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				13,762
D. PERMANENT EQUIPMENT See below				12,100
E. EXPENDABLE EQUIPMENT AND SUPPLIES				5,100
F. TRAVEL 1. Domestic (Including Canada)				900
2. Foreign IUGG Meeting (Grenoble, France)				1,200
G. PUBLICATION COSTS				700
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				450
I. OTHER DIRECT COSTS				
J. TOTAL DIRECT COSTS (C through I)				34,212
K. INDIRECT COSTS 46.2% of $12,385				5,722
L. TOTAL COSTS (J plus K)				39,934
Residual Balance at 12/31/74				20,450
M. ~~[illegible]~~ Adjusted Request				$ 19,484

REMARKS: Use extra sheet if necessary

D. Permanent Equipment:

Thermal Conductivity Apparatus & Furnace	$6,500
Decade Resistor Bos	500
Digital Voltmeter	1,400
Digital Thermometer	1,900
Freq. Counter	700
Oscillator	1,100

REVISION TO PHASE II PROPOSAL

HAWAII GEOTHERMAL PROJECT

ENGINEERING PROGRAM

This revision to the Hawaii Geothermal Project Phase II Proposal summarizes the changes in the 1975 Engineering Program necessitated by a reduction in the proposed budget. Narrative summaries of the required work changes and revised task timetables follow. The revised budgets for the individual tasks are included with the narrative portion in this section, while the budget summary for the total Engineering Program appears earlier in the Overview Section of this proposal revision.

The revised budget for the Engineering Program for 1975 totals $160,000. However, there will be $9,000 in unencumbered funds that will carry over from Phase I, so the total amount for Engineering requested from NSF in this proposal revision equals $151,000. Both total budget and NSF support requested in this proposal are shown on the budget worksheets.

TASK 3.0 ENGINEERING SUPPORT AND COORDINATION

A. Changes in Support and Coordination Effort

The reduced budget necessitates a reduction in the previously planned Engineering effort and a delay in the achievement of Engineering Program objectives. The consultant fee for Rogers Engineering for initial geothermal power plant design and funds for undergraduate student help for report typing and clerical work have been dropped from the budget. Also, the fee for John F. Mink for consulting on ground water problems has been reduced.

TASK 3.1 GEOTHERMAL RESERVOIR ENGINEERING

A. Changes in Research Effort

Because of the reduced budget request, the effort described in the Phase II Proposal for Task 3.1, Geothermal Reservoir Engineering, will be scaled down, resulting in a three- to six-month delay of target dates for some aspects of the work and indefinite postponement of other aspects.

The new target date for the completion of the analyses of steady pumping and reinjection in a hot-brine reservoir and of the dynamics of the Ghyben-Herzberg lens will be August, 1975. The initiation of the analytical work on the problem of transient responses in a hot-brine reservoir will be postponed until the latter part of Phase II. The problem of boiling heat transfer in two-phase flow will not be investigated in 1975. The writing of a general computer code for the simulation of Hawaii geothermal reservoirs, taking into consideration the anisotropic properties of rock formation, the irregular geometry of boundaries, and the presence of dikes will be deferred until 1976.

Both the well test/analysis and physical model assembly will be forced to proceed at a slower pace with reduced funding. Plans for obtaining on-the-job experience in New Zealand and/or the Geysers, California, will be postponed until 1976.

Revised timetables for the two subtasks follow.

B. Revised Timetable

1. Numerical Modelling of Geothermal Reservoirs

Investigators: P. Cheng, K. H. Lau, and L. S. Lau

December 31, 1974	1. Complete investigation of the effect of vertical heat source on the upwelling of the water table 2. Formulate finite element solution of free convection in a geothermal reservoir with irregular geometry
August 31, 1975	1. Complete investigation of the effects of geothermal heating on Ghyben-Herzberg lens 2. Complete numerical solutions for heat transfer and fluid flow characteristics in an axisymmetric geothermal reservoir 3. Complete numerical solution of steady state pumping and reinjection in a confined geothermal reservoir
December 31, 1975	1. Complete finite element solution of free convection in a two-dimensional geothermal reservoir with irregular geometry 2. Formulate problem of transient responses in geothermal reservoirs with pumping and reinjection
December 31, 1976	1. Complete investigation of transient responses in geothermal reservoirs with pumping and reinjection 2. Refine finite element computer code to take into consideration various effects

TASK 3.1 (Continued)

2. Well Test Analysis and Physical Modelling

Investigators: P. Takahashi, B. Chen, and L. S. Lau

December, 1974	1. Select hardware for well testing 2. Assess software for well testing 3. Complete initial phase of the fabrication of the physical model 4. Develop well test analysis methodology in conjunction with Geophysics Drilling Program 5. Initiate computer program on well test analysis
May, 1975	1. Purchase hardware and select software for well testing (with Geophysics Program) 2. Initiate laboratory parametric checks 3. Assess methods for measurement and analysis of two-phase flow 4. Design Ghyben-Herzberg lens physical model 5. Develop computer program to combine type curve matching and mass/energy balance into a single predictive tool
September, 1975	1. Initiate laboratory simulation studies 2. Fabricate Ghyben-Herzberg lens physical model 3. Purchase equipment to interface the different physical models
December, 1975	1. Analyze laboratory simulation runs and correlate with computer model 2. Interface physical models into a general model of a geothermal field 3. Develop methods for two-phase flow measurement and analysis 4. Measure temperature, pressure and flow rate--both donwhole and at wellhead 5. Analyze data
December, 1976	1. Complete analysis of geothermal well data 2. Predict geothermal field performance

TASK 3.6 OPTIMAL GEOTHERMAL PLANT DESIGN

A. Changes in Research Effort

The reduced budget request has necessitated a reduction in the originally proposed effort and a delay in the completion of subtasks. The detailed design of the proposed research-oriented power plant will not be initiated during 1975. Preparatory work will be continued, but at a slower pace. The experimental test portion of the research will be concentrated primarily on a study of heat transfer in horizontal tube bundles. The vertical configuration will be investigated during the following year.

A revised timetable for Task 3.6 follows.

TASK 3.6 OPTIMAL GEOTHERMAL PLANT DESIGN

Investigators: H. C. Chai, J. Chou, and D. Kihara

B. Revised Timetable

December 31, 1974	1. Survey availability of components to be used with each working fluid 2. Construct components and assemble experimental heat transfer loop
June 30, 1975	1. Establish general requirements, ground rules, and design criteria for a research-oriented plant for liquid-dominated fields 2. Construct and test horizontal heat exchanger
December 31, 1975	1. Set up procedures for the design and selection of the components of regenerative binary fluid plants 2. Continue testing of horizontal heat exchanger and write computer program for horizontal heat exchanger 3. Begin testing of vertical heat exchanger
June 30, 1976	1. Lay out detailed flow diagrams of the plant based on a regenerative binary fluid system, with a vapor flashing system as the alternative 2. Analyze test data for horizontal heat exchanger and continue testing of vertical heat exchanger
December 31, 1976	1. Estimate capital costs of the plant, evaluate unit operating cost, and compare feasibilities of the two systems 2. Complete testing and analyze test data for vertical heat exchanger

ENGINEERING PROGRAM
Task 3.0

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT
BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Paul C. Yuen

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. 1 (Co) Principal Investigator(s)			1.0	$ 2,996*
b. ____ Faculty Associates				
Sub-Total				2,996
2. Other Personnel (Non-Faculty)				
a. ____ Research Associates–Postdoctoral				
b. ____ Non-Faculty Professionals				
c. ____ Graduate Students				
d. ____ Pre-Baccalaureate Students				
e. 1 Secretarial–Clerical				9,036
f. ____ Technical, Shop, and Other				
TOTAL SALARIES AND WAGES				12,032
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				1,862
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				13,894
D. PERMANENT EQUIPMENT				
E. EXPENDABLE EQUIPMENT AND SUPPLIES				600
F. TRAVEL 1. Domestic (Including Canada)				1,900
2. Foreign				
G. PUBLICATION COSTS				900
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				
I. OTHER DIRECT COSTS Consultant Fee 500 Communications 527				1,027
J. TOTAL DIRECT COSTS (C through I)				18,321
K. INDIRECT COSTS 46.20% of Salaries & Wages				5,559
L. TOTAL COSTS (J plus K)				23,880
Residual Balance at 12/31/74				1,000
M. ~~AMOUNT OF THIS AWARD (ROUNDED)~~ Adjusted Request				$ 22,880

REMARKS: Use extra sheet if necessary

*Includes anticipated 10% salary increase

ENGINEERING PROGRAM
Task 3.1

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Paul C. Yuen

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. ______ (Co) Principal Investigator(s)				$
b. 5 Faculty Associates		2.25	8.0	21,021*
Sub-Total				21,021
2. Other Personnel (Non-Faculty)				
a. ______ Research Associates--Postdoctoral				
b. ______ Non-Faculty Professionals				
c. 4 Graduate Students				16,944
d. 1 Pre-Baccalaureate Students				2,200
e. ______ Secretarial--Clerical				
f. ______ Technical, Shop, and Other				
TOTAL SALARIES AND WAGES				40,165
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				2,297
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				42,462
D. PERMANENT EQUIPMENT				
E. EXPENDABLE EQUIPMENT AND SUPPLIES				
F. TRAVEL 1. Domestic (Including Canada)				4,200
2. Foreign				
G. PUBLICATION COSTS				1,100
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				3,500
I. OTHER DIRECT COSTS Communications				470
J. TOTAL DIRECT COSTS (C through I)				51,732
K. INDIRECT COSTS 46.20% of Salaries & Wages				18,556
L. TOTAL COSTS (J plus K)				70,288
Residual Balance at 12/31/74				4,000
M. ~~AMOUNT OF THIS AWARD (ROUNDED)~~ Adjusted Request				$ 66,288

REMARKS: Use extra sheet if necessary

*Includes anticipated 10% salary increase

ENGINEERING PROGRAM
Task 3.6

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Paul C. Yuen

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. ____ (Co) Principal Investigator(s)				$
b. 3 Faculty Associates		2.25	5.0	17,091*
Sub-Total				17,091
2. Other Personnel (Non-Faculty)				
a. ____ Research Associates—Postdoctoral				
b. ____ Non-Faculty Professionals				
c. 2 Graduate Students				9,072
d. 2 Pre-Baccalaureate Students				2,000
e. ____ Secretarial—Clerical				
f. 1 Technical, Shop, and Other				4,650
TOTAL SALARIES AND WAGES				32,813
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				1,625
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				34,438
D. PERMANENT EQUIPMENT See below				5,600
E. EXPENDABLE EQUIPMENT AND SUPPLIES				3,000
F. TRAVEL 1. Domestic (Including Canada)				3,300
2. Foreign				
G. PUBLICATION COSTS				1,000
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				3,000
I. OTHER DIRECT COSTS Communications				334
J. TOTAL DIRECT COSTS (C through I)				50,672
K. INDIRECT COSTS 46.20% of Salaries & Wages				15,160
L. TOTAL COSTS (J plus K)				65,832
Residual Balance at 12/31/74				4,000
M. ~~[illegible]~~ Adjusted Request				$ 61,832

REMARKS: Use extra sheet if necessary

*Includes anticipated 10% salary increase

D. PERMANENT EQUIPMENT:

Pump	400	Digital Ammeter	700
Temperature Controller (2)	500	Digital Voltmeter	700
Differential Pressure Gage (2)	600	Misc. & Shipping	1,700
Density Gage (2)	1,000	TOTAL	5,600

HAWAII GEOTHERMAL PROJECT
PHASE II PROPOSAL REVISION
SOCIOECONOMIC AND ENVIRONMENTAL PROGRAM

In consideration of (i) the budget limits placed upon this program while the geothermal resources of Hawaii are being researched and (ii) the recent grant of NSF funds to the Hawaii Department of Planning and Economic Development for its complementary research on the application of geothermal development in this state, the following reductions have been made in our program proposal and budget:

1. Economic research (Task 4.4) is for the time being limited to: (i) carrying through to completion the study of energy use in Hawaii; (ii) continuing the inventory of geothermal production units around the world and noting their operational costs; (iii) applying a Bayesian feasibility model to decision-making on geothermal investment; and (iiii) constructing an econometric model of the local economy which isolates the effects of changes in energy inputs.

Both the specialness of the Hawaii case, and the elements of its economy more or less common to other areas of the United States, will continue to be noted, but broader analyses -- such as by-product utilization -- will be postponed.

Only limited attention will be given in 1975 to the economics of electrical production (from geothermal resources) itself, e.g. the effects of economies of scale on the per unit cost of producing electrical energy with generating facilities of various capacities. However, we will be available to provide economic input for the Engineering program in its research into plant design.

2. Environmental investigation (Task 4.1) will be confined to establishing base line data at the Puna drill site area and monitoring drilling as it occurs, including identification of flora and fauna on which there may be an impact. Particular attention will be given to possible effects on the Ghyben-Herzberg lens which might affect ground water supplies in the Puna region.

In other areas of environmental concern, only the minimal work necessary for an environmental impact statement will be completed.

3. The legal-regulatory task (4.2) will be limited to maintaining the research contributions of an unpaid consultant attorney, Mr. Donald Kornreich of NASA/Ames, who while at the University of Hawaii last academic year developed an interest in the project.

The draft of regulations to govern geothermal operations, already prepared by this task, with the assistance of David N. Anderson of the California Department of Conservation, will be made available to the Hawaii State Department of Land and Natural Resources, which has responsibility for administration of Hawaii's 1974 geothermal development law, including regulation of drilling and production.

4. The land use-planning task (4.3) as a research project will be put aside for the next calendar year; it will depend on liaison with the project of the Hawaii Department of Planning and Economic Development for maintaining an understanding of how geothermal discovery and development will be affected by planning, zoning and land-use regulation of the State and of the County of Hawaii.

However, we will continue with the practical task of assisting our drilling program to get permission to use land in the Puna area selected as the site for exploratory drilling. This requires negotiations with the landowners for right of entry and for right of production in the event a useful geothermal source is discovered, and consultation with state and county authorities which govern land use on the Island of Hawaii. The right-of-entry agreement now being negotiated will require implementation of contingency provisions written into it to cover the event that a commercially significant geothermal field is tapped by the exploratory drilling. We will continue to offer advisory services to the drilling program with respect to state and county requirements as the drilling progresses.

No separate budget is projected for this task; it is subsumed under Task 4.0 -- Program Administration and Support.

As revised, the socioeconomic and environmental program is essentially at a plateau. It will continue (and in some areas complete) the tasks begun in the first phase of the project and will open up new areas of investigation only in environmental observations, which are required by the undertaking of exploratory drilling on the Island of Hawaii. It will undertake responsibility for obtaining from the University and the State of Hawaii the legal services needed to assure that a site is available for exploratory drilling.

The budgetary effects of this revision of tasks are to reduce the overall request for the Socioeconomic-Environmental program in 1975 by more than half -- from $131,763 to $62,772. The revised budgets for each of the individual tasks follow, while the budget summary for the entire Socioeconomic and Environmental Program appears earlier in the Overview Section of this proposal revision. A carry-over of $9,772 in unencumbered funds from Phase I further reduces the new support requested from NSF to $53,000.

PROGRAM ADMINISTRATION AND SUPPORT

Task 4.0

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Robert M. Kamins

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. ____ (Co) Principal Investigator(s)		3	1	$ 12,500*
b. ____ Faculty Associates				
Sub-Total				12,500*
2. Other Personnel (Non-Faculty)				
a. ____ Research Associates—Postdoctoral				
b. ____ Non-Faculty Professionals				
c. ____ Graduate Students				
d. 1 Pre-Baccalaureate Students				2,000
e. ____ Secretarial—Clerical				
f. ____ Technical, Shop, and Other				
TOTAL SALARIES AND WAGES				14,500
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				1,539
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				16,039
D. PERMANENT EQUIPMENT				
E. EXPENDABLE EQUIPMENT AND SUPPLIES				200
F. TRAVEL 1. Domestic (Including Canada)				400
2. Foreign				
G. PUBLICATION COSTS				
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				
I. OTHER DIRECT COSTS				
J. TOTAL DIRECT COSTS (C through I)				16,639
K. INDIRECT COSTS 46.20% of Salaries & Wages				6,699
L. TOTAL COSTS (J plus K)				23,338
Residual Balance at 12/31/74				3,549
M. ~~AMOUNT OF THIS AWARD REQUESTED~~ Adjusted Request				$ 19,789

REMARKS: Use extra sheet if necessary

*Includes anticipated 10% salary increase

NSF FORM 569, JULY 1971 SUPERSEDES ALL PREVIOUS EDITIONS

ENVIRONMENTAL

Task 4.1

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Robert M. Kamins

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. ____ (Co) Principal Investigator(s)				$
b. 2 Faculty Associates	1		1	3,200
Sub-Total				3,200
2. Other Personnel (Non-Faculty)				
a. ____ Research Associates—Postdoctoral				
b. ____ Non-Faculty Professionals				
c. 1 Graduate Students (Part-Time)				1,000
d. ____ Pre-Baccalaureate Students				
e. ____ Secretarial—Clerical				
f. ____ Technical, Shop, and Other				
TOTAL SALARIES AND WAGES				4,200
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				330
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				4,530
D. PERMANENT EQUIPMENT Reagent Kits 720 3 Hi.-Vol. Samplers 1080; Electric Fld. Srce 420				2,220
E. EXPENDABLE EQUIPMENT AND SUPPLIES				100
F. TRAVEL 1. Domestic (Including Canada)				1,200
2. Foreign				
G. PUBLICATION COSTS				
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				
I. OTHER DIRECT COSTS				
J. TOTAL DIRECT COSTS (C through I)				8,050
K. INDIRECT COSTS 46.20% of Salaries & Wages				1,940
L. TOTAL COSTS (J plus K)				9,990
Residual Balance at 12/31/74				4,212
M. Adjusted Request				$ 5,778

REMARKS: Use extra sheet if necessary

NSF FORM 569, JULY 1971 SUPERSEDES ALL PREVIOUS EDITIONS

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Robert M. Kamins

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. ______ (Co) Principal Investigator(s)				$
b. ______ Faculty Associates				
Sub-Total				
2. Other Personnel (Non-Faculty)				
a. ______ Research Associates—Postdoctoral				
b. ______ Non-Faculty Professionals				
c. ______ Graduate Students				
d. ______ Pre-Baccalaureate Students				
e. ______ Secretarial—Clerical				
f. ______ Technical, Shop, and Other				
TOTAL SALARIES AND WAGES				
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				
D. PERMANENT EQUIPMENT				
E. EXPENDABLE EQUIPMENT AND SUPPLIES				
F. TRAVEL 1. Domestic (Including Canada)				800
2. Foreign				
G. PUBLICATION COSTS				
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				
I. OTHER DIRECT COSTS				
J. TOTAL DIRECT COSTS (C through I)				800
K. INDIRECT COSTS				
L. TOTAL COSTS (J plus K)				800
Residual Balance at 12/31/74				800
M. ~~AMOUNT OF THIS REQUEST~~ Adjusted Request				$ 0

REMARKS: Use extra sheet if necessary

ECONOMICS

Task 4.4

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Robert M. Kamins

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. 1 (Co) Principal Investigator(s)		3	0	$ 9,400*
b. 3 Faculty Associates			2	4,280*
Sub-Total				13,680*
2. Other Personnel (Non-Faculty)				
a. ___ Research Associates—Postdoctoral				
b. ___ Non-Faculty Professionals				
c. 1 Graduate Students				550
d. ___ Pre-Baccalaureate Students				
e. 1 Secretarial—Clerical (50%)				4,000
f. ___ Technical, Shop, and Other				
TOTAL SALARIES AND WAGES				18,230*
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				1,592
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				19,822
D. PERMANENT EQUIPMENT				
E. EXPENDABLE EQUIPMENT AND SUPPLIES				100
F. TRAVEL 1. Domestic (Including Canada)				200
2. Foreign				
G. PUBLICATION COSTS				
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				100
I. OTHER DIRECT COSTS				
J. TOTAL DIRECT COSTS (C through I)				20,222
K. INDIRECT COSTS 46.20% of Salaries and Wages				8,422
L. TOTAL COSTS (J plus K)				28,644
Residual Balance at 12/31/74				1,211
M. ~~AMOUNT OF THIS AWARD REQUEST~~ Adjusted Request				$ 27,433

REMARKS: Use extra sheet if necessary

*Includes anticipated 10% salary increase

Proposal for Research Deep Hole Drilling

Management and Support

Task 5.0

Agatin T. Abbott

Introduction

As the various avenues of research and exploration which have been described earlier in this report are being completed or are in various stages of completion, it becomes clear that the next logical step in the search for geothermal energy on the island of Hawaii is to test beneath the surface by drilling.

Previous Work

The drilling program is based on the results of a number of other lines of investigation and research that have been carried out during earlier stages of the Hawaii Geothermal Project. Reference is made to tasks under Phase I Geophysics, Tasks 2.1 Photogeologic; 2.2, 2.4 Electromagnetic; 2.3 Electrical Resistivity; 2.5 Microseismic. Reference is also made under Phase I Extension Geophysics, Tasks 2.1 Preparation for Exploratory Drilling; 2.2 Geoelectric; 2.3 Gravity and Magnetic; 2.4 Thermal; 2.5 Microseismic; 2.6 Geochemical. Under Engineering,Task 3.1 Reservoir Engineering; and under Environmental-Socioeconomic, Tasks 4.3, 4.4, 4.5 Legal and Planning. Most of the preparatory effort has been concentrated in the Puna area.

A large amount of information is contained in earlier works on the geology and groundwater hydrology of portions of the island of Hawaii that was not done for the express purpose of gaining geothermal information. These references are provided at the end of this chapter.

Personnel

Because the exploratory and research drilling program of the Hawaii Geothermal Project is very large, both in terms of financial involvement and also in terms of the fields of interest that it encompasses, the personnel to manage this phase is as follows:

Co-principal Investigator and Director of Exploratory Drilling

Agatin T. Abbott, Geology and Management
University of Hawaii

Site Selection and Operations Committee

Agatin T. Abbott - Geology, Univ. of Hawaii
Pow-foong Fan - Geochemistry, Univ. of Hawaii
Augustine S. Furumoto - Geophysics, Univ. of Hawaii
Gordon A. Macdonald - Geology, Univ. of Hawaii
Donald Peterson - Geology, U.S. Geol. Survey
Charles Zablocki - Geophysics, U.S. Geol. Survey

The role of the Site Selection and Operations Committee is a decision-making one regarding all phases of the drilling program and integration of the drilling program with other phases of the HGP such as Geophysics, Engineering, and Legal and Socio-economics. There must be a close association between the several fields of interest in this project, if the maximum benefit is to be achieved from the holes drilled.

In order to have as large an input as possible from knowledgeable persons who are in one way or another concerned with geothermal energy, a large body of advisors has been invited to contribute ideas and suggestions as the project continues. There will undoubtedly be additional names added as time goes along, but at the present time the following persons comprise the Advisory Group:

David Anderson - State of California Resources

Kenneth Brunot - National Science Foundation (formerly Phillips Petro.Co.)

Dan Davis - U.S.G.S.

Robert Kamins - University of Hawaii

Douglas Klein - University of Hawaii

George Keller - Colorado School of Mines

George Kennedy - University of California, L.A.

Kost Pankiwskyj - University of Hawaii

Henry Ramey - Stanford University

Robert Rex - Republic Geothermal Company

Fred Smales - Hawaiian Cement Company

Harold Stearns - U.S.G.S., retired

Robert Tilling - U.S.G.S.

John Unger - U.S.G.S.

Donald White - U.S.G.S.

George Woollard - Hawaii Institute of Geophysics

Paul Yuen - University of Hawaii

During the time drilling is going on close supervision will be required to watch the drill cuttings and to inform the Director of Drilling and the Site Selection and Operations Committee of significant changes in the rock type, structural features, temperature and other parameters which, for one thing, could have a strong influence on the decision to take rock cores. For this purpose the employment of two graduate and two undergraduate students is planned. Student assistance will also be required after the drilling is completed to help log the core and perform other duties.

During the drilling a good deal of travel between Oahu and Hawaii will be required for the co-principal investigator, members of the drilling committee and student assistants. The co-principal investigator is planning on two mainland visits for meetings and conferences and on a trip to Iceland which is probably the most comparable area geologically to Hawaii.

General

Macdonald, G.A. and Abbott, A.T., Volcanoes in the Sea, University Press of Hawaii, 441 pages, 1970.

Stearns, H.T. Geology of the State of Hawaii, Pacific Books, Palo Alto, California, 1966.

Stearns, H.T. and Macdonald, G.A., Geology and Ground Water Resources of the Island of Hawaii, Hawaii Division of Hydrography, Bull. 9, 363 pp., and colored geologic map, 1946.

Specific

Macdonald, G.A., Geological Prospects for Development of Geothermal Energy in Hawaii, Pacific Sicence, v. 27, no. 3, pp. 209-219, 1973.

Hawaii Geothermal Project

Task 5.1 Drilling

Agatin T. Abbott

Introduction and Review

The geothermal drilling plans on the island of Hawaii as expressed in the earlier proposal of July 1974 have by necessity been curtailed. Because of inconclusive and incomplete geophysical results in areas along the southwest rift zone of Kilauea and also along the southwest rift zone of Mauna Loa in the vicinity of South Point exploratory drilling in these sections has been postponed. The east rift zone of Kilauea continues to appear the most favorable from the point of view of geological and geophysical conditions, so it is in the area of Kilauea lower east rift close to an offset in the trend of the rift at an elevation of approximately 600 feet above sea level that a drilling on a self-potential anomaly appears warranted.*

Rationale for Drilling

With a limited amount of NSF funding for drilling and with mounting costs of drilling since last year, decisions must be reached as to how the money available for drilling should best be spent. Two main alternatives exist.

One is to use the funds to drill a series of shallow holes in the Puna area for the purpose of obtaining additional underground information on temperatures and water conditions without any intent of drilling into deeper zones where we believe the potential geothermal resource may exist. The second option is to locate a hole on the basis of our knowledge of

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*Refer to Macdonald, pp. 260-270 and Zablocki, pp. 271-274 in July 1974 proposal.

the geology and geophysics to date coupled with information from already drilled water wells, and to spend all the funds available for fiscal 1975 in pushing one hole to as great a depth as can be achieved with the funds available.

The second option is the one considered to be the most desirable by the Director of Drilling and by all the members of the Site Selection and Operations Committee.

It is felt that the amount of new information to be gained on the shallow holes does not justify the expenditure of the funds. On the other hand, probing to depths where we now have no factual information would be most beneficial and we could conceivably arrive in the upper portion of a potential geothermal resource. It is also unanimously agreed by the Director of Drilling and the Site Selection Committee that the funds presently available in fiscal 1975 are not sufficient to allow drilling to a critical depth of approximately 6000 feet. If conditions toward the bottom of a hole drilled in fiscal 1975 are improving, it would be the intention of the drilling committee to request additional funds for fiscal 1976 to deepen the hole, and based on the results of that hole to drill additional holes.

At the present level of funding a hole of approximately 3500 foot depth can be drilled.

Changes in Plans for Drilling

In the July 1974 proposal for the exploratory drilling program in three areas on the island of Hawaii, it was proposed that an engineering firm, such as Rogers Engineering of San Francisco, be retained to plan and direct a rather extensive drilling program. Under the old plan consideration was given to competitive bidding between drilling contractors both local and mainland.

The revised plan to drill only one hole in fiscal 1975 forces canceling of plans for an engineering firm to act as manager in order to conserve funds and to put the maximum number of dollars to work on the principal effort, namely, drilling the hole to as great a depth as possible.

Similarly, the consideration of mainland drilling contractors becomes impractical as it is quite obvious that no drilling firm will travel to Hawaii to drill one hole, or if they did the costs of mobilization alone would be greater than the funds available for drilling.

We have concluded, therefore, that we will not employ an engineering firm as drilling manager, and that we are constrained to employ the services of local drillers.

From among the several local drilling companies whose usual assignments are drilling water wells, only one has a drilling rig that will hopefully reach the ultimate depth of 6000 feet as we recommend.

This company is Water Resources International, 2828 Paa Street, Honolulu, Hawaii 96819, Mr. E.C. Craddick, President. The drilling rig that they would use on the Hawaii Geothermal Project in Puna is the same rig that drilled the 4200 foot hole at the summit of Kilauea in 1973 for Dr. George Keller, Colorado School of Mines. It is a Spencer-Harris 6000 Rotary rig with a 100 foot tower. The company president, Mr. Craddick, has stated in conversation that he feels confident that the rig can drill to a depth of 6000 feet.

The advantages of using the drilling services of Water Resources International are that the drill rig is presently in the islands and mobilization costs will be considerably less than for a mainland rig, and that the drillers who are employed by Water Resources International are experienced in drilling in Hawaiian lava flows as well as benefiting from the experience of drilling the deep hole for geothermal information at Kilauea's summit.

Down Hole Testing

During the course of the drilling it is planned to employ the services of Schulumberger Inc. or a similar firm which is equipped and experienced in making down hole measurements. Frequent measurements of temperatures in the hole will be made during the drilling. At the conclusion of the drilling a complete survey of the hole is planned for all physical and chemical parameters deemed important by the Site Selection and Operations Committee. Also during the drilling time will be allowed for the obtaining of water samples at critical horizons.

Rock cores will be taken at critical depths and where possible where major changes in lithology occur. It is planned to obtain sufficient cores for information on rock characteristics at depth, but not to the point where coring causes serious delays or excessive expenditures of funds.

It is the rationale of the Director of Drilling and the members of the Site Selection and Operations Committee that the primary objective is to achieve the deepest hole possible commensurate with the gathering of vital and relevant scientific data. Scientific data gathering during the drilling of the hole must be adequate but held to a minimum.

After the hole is completed, depending of course on the behavior of any geothermal fluids that may have been tapped, the hole will be available for a host of engineering,geophysical, geochemical and hydrologic tests.

Location of the Hole Relative to the Self-Potential Anomaly and to Land Ownership

Based on evidence presented earlier in the Geophysics section a strong self-potential anomaly lies to the north of Puulena pit crater. The decision to drill as close as possible to the apex of the self-potential anomaly was reached by the Site Selection committee in early October.

Land ownership which is discussed under the Legal Section of this proposal plays an important role in reaching a decision on the final location. At the present time two drill hole locations are being considered as shown in Figures 2 and 3 .

The most favorable location is shown close to the apex of the anomaly and is indicated by the designation 1 $\boxed{X}$ on Figure 3 . This location falls within the second increment of the Lanipuna Estates subdivision. The managers of this subdivision, Tokyu Land Co. of Japan, may be agreeable to drilling within this increment; however, final agreement with them has not been reached.

In case permission for the drilling on the first choice location is not granted, an alternative site has been selected, shown by the designation 2 $\boxed{X}$ on Figure 2 which falls on the property of Kapoho Land and Development Co. which is a portion of the Lyman Estate.

Although the alternative hole location does not fall on such a favorable area relative to the self-potential anomaly as does the primary location, it is in a relatively favorable geologic position, and may present many fewer legal problems.

It is the consensus of the Site Selection Committee that at depths of 3500 feet or more that if the potential geothermal resource is so limited in size that if we drill 1,500 feet or so off the apex of the self-potential anomaly and are unsuccessful in finding a geothermal resource that the extent of the resource must be so limited as to be of little economic importance.

In conclusion, if the Tokyu Co. land ownership problems are satisfactorily reached, the drill hole location will be as shown 1 [X] on Figure 2 and Figure 3. If those land arrangements cannot be resolved the alternative location will be chosen on lands owned by the Kapoho Land and Development Co.

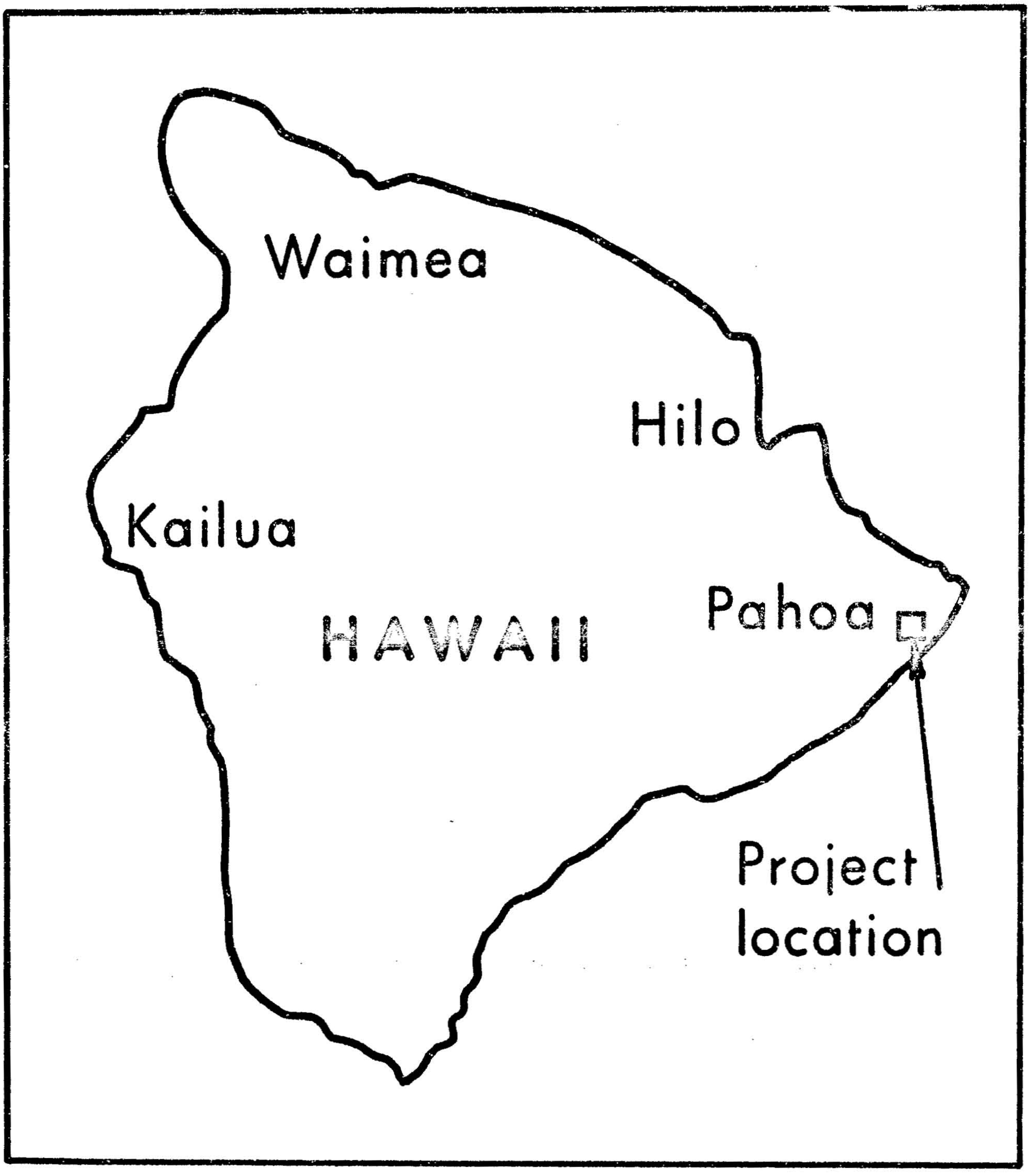


Figure 1. Location Map of Proposed Drilling Project

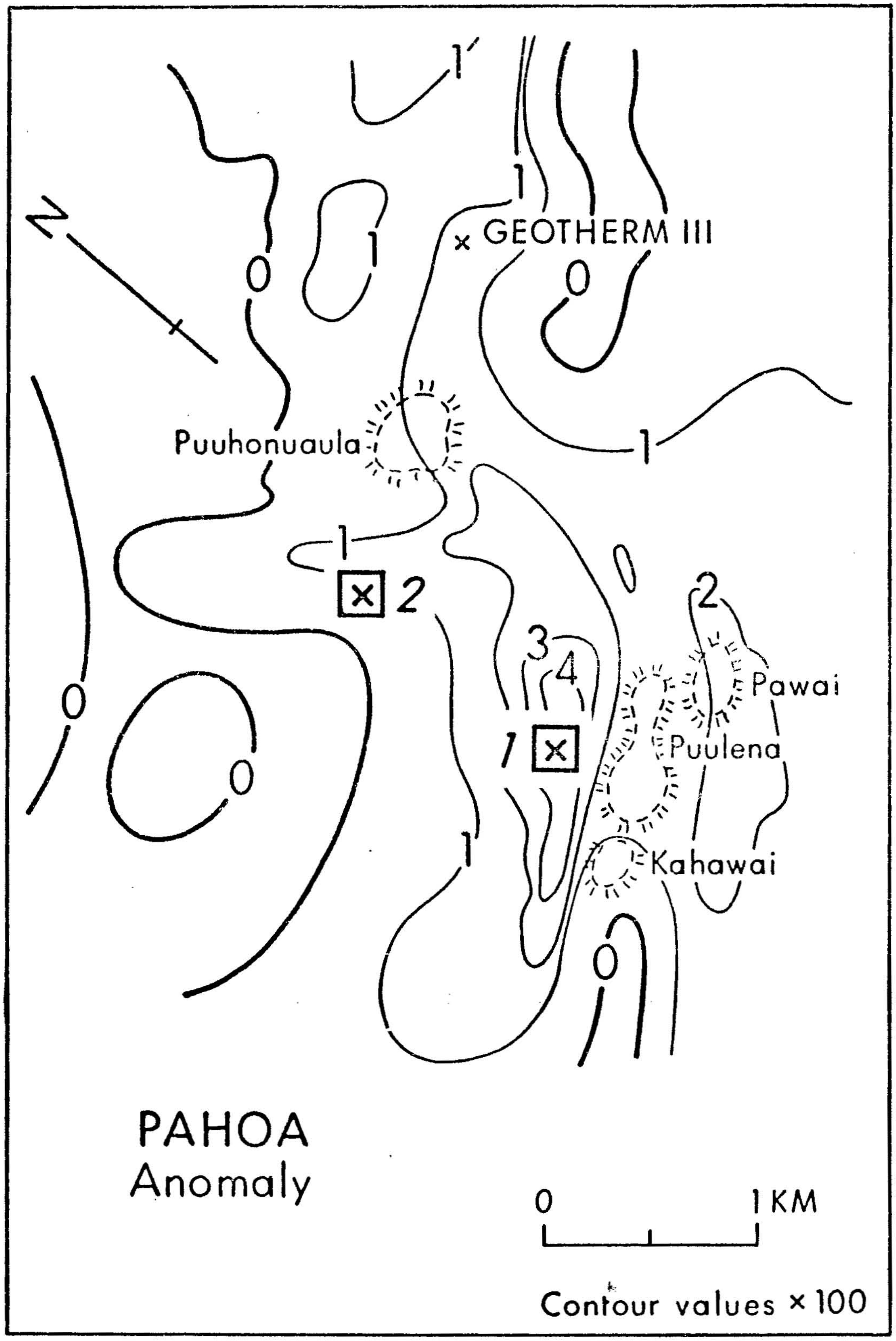


Figure 2. Location of Proposed Drill Sites Superimposed on Self-potential Anomaly. Location 1 [X] is favored. Location 2 [X] is the alternative.

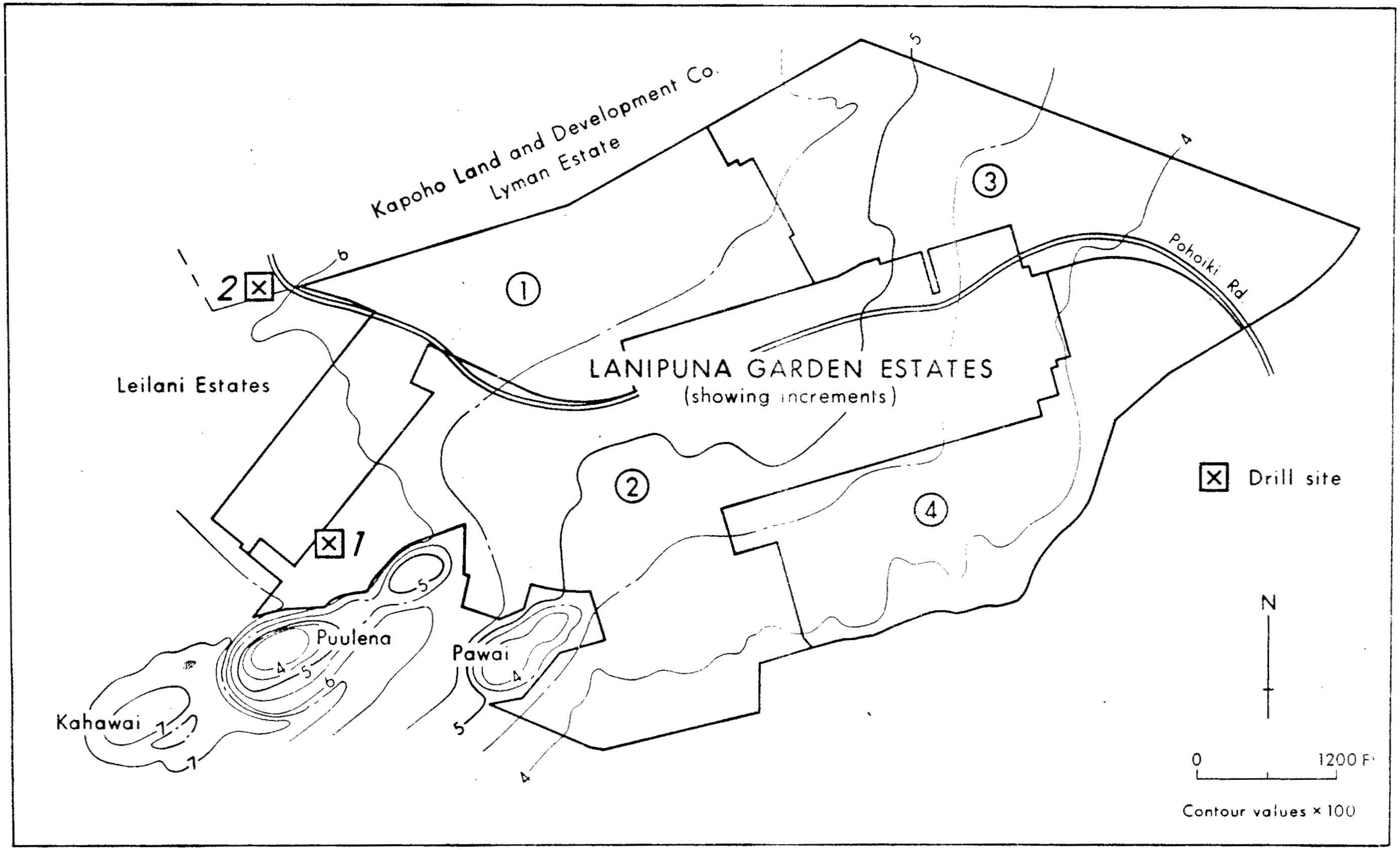


Figure 3. Location of Proposed Drill Hole Sites Superimposed on Land Ownership Map.
Site 1 [X] is more favorable based on geophysical results. Site 2 [X] is an alternate location with possibly less complex land ownership problems.

COST ESTIMATE FOR DRILLING PROGRAM

Figures were furnished by Mr. E.C. Craddick,
President, Water Resources International

I.	Setup Costs		
	1) Mobilization	$ 25,000	
	2) Demobilization	20,000	
	3) Pit construction and blow out equipment	25,000	
	4) Sub-structure	30,000	
	Total		$100,000
II.	Equipment and Crew @ $225/hour based on estimate of 100 feet of drilling per 24 hour day to reach a depth of 3,500 feet--includes coring as necessary		189,000
III.	Material		
	1) Drill stem for 3,500 foot hole	70,000	
	(less salvageable stem)	(35,000)	
	2) Bentonite drilling mud 3,500 bags @ $5.00	17,500	
	3) Zeogel drilling mud 2,300 bags @ $7.50	17,250	
	4) Revert drilling fluid 580 bags @ $10.00	5,800	
	5) Rock bits 7-7/8" 35 ea. @ $600.00	21,000	
	6) Hole opener 12" 10 ea. @ $800.00	8,000	
	7) Hole opener 16" 6 ea. @ $1,600.00	9,600	
	8) Casing 14" 1,000 ft. @ $20.00	20,000	
	9) Casing 10" 1,000 ft. @ $15.00	15,000	
	10) Core bits (diamond) 3 ea. @ $3,000	9,000	
	11) Hauling charges	10,000	
	Total		168,150
IV.	Other Charges		
	1) Well testing	25,000	
	2) Management and support	20,863	
	Total		45,863
V.	Contingency (Any unused portion may be applied to additional drilling.)		76,850
	Total Cost of Drilling Program		$579,863

MANAGEMENT AND SUPPORT

Task 5.0

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Agatin T. Abbott

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. 1 (Co) Principal Investigator(s)			1	$ 3,100 *
b. ___ Faculty Associates				
Sub-Total				3,100
2. Other Personnel (Non-Faculty)				
a. ___ Research Associates—Postdoctoral				
b. ___ Non-Faculty Professionals				
c. 2 Graduate Students				2,000
d. 2 Pre-Baccalaureate Students				1,000
e. 1 Secretarial—Clerical				2,000
f. 1 Technical, Shop, and Other				1,000
TOTAL SALARIES AND WAGES				9,100
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				1,183
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				10,283
D. PERMANENT EQUIPMENT Equipment to handle drill cores				1,000
E. EXPENDABLE EQUIPMENT AND SUPPLIES				1,000
F. TRAVEL 1. Domestic (Including Canada) Interisland + perdiem; 2 mainland + per diem				1,500
2. Foreign Iceland + per diem				1,500
G. PUBLICATION COSTS				500
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				
I. OTHER DIRECT COSTS Communications $500 Field office - trailer . 800				1,300
J. TOTAL DIRECT COSTS (C through I)				17,083
K. INDIRECT COSTS 46.2% of $6,100 = $2,818 34.13% of 3,000 = 1,024 $9,100				3,842
L. TOTAL COSTS (J plus K)				20,925
M. AMOUNT OF THIS AWARD (ROUNDED)				$

REMARKS: Use extra sheet if necessary

*Includes anticipated 10% salary increase

DRILLING

Task 5.1

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET WORKSHEET

INSTITUTION AND ADDRESS	NSF PROGRAM	PRINCIPAL INVESTIGATOR(S)
University of Hawaii Honolulu, Hawaii 96822	HAWAII GEOTHERMAL PROJECT	Agatin T. Abbott

PROPOSAL NUMBER	RECOMMENDED DURATION	GRANT NO.	RECOMMENDED GRANT AMOUNT
			$

	NSF Funded Man Months (to the nearest tenth) Cal.	Acad.	Summ.	NSF GRANT BUDGET
A. SALARIES AND WAGES				
1. Senior Personnel				
a. ______ (Co) Principal Investigator(s)				$
b. ______ Faculty Associates				
Sub-Total				
2. Other Personnel (Non-Faculty)				
a. ______ Research Associates—Postdoctoral				
b. ______ Non-Faculty Professionals				
c. ______ Graduate Students				
d. ______ Pre-Baccalaureate Students				
e. ______ Secretarial—Clerical				
f. ______ Technical, Shop, and Other				
TOTAL SALARIES AND WAGES				
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				
D. PERMANENT EQUIPMENT				
E. EXPENDABLE EQUIPMENT AND SUPPLIES				
F. TRAVEL 1. Domestic (Including Canada)				
2. Foreign				
G. PUBLICATION COSTS				
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				
I. OTHER DIRECT COSTS Mobilization and setup $100,000 Equipment and crew 189,000 - 35 days Material and contingencies 245,000 Well testing 25,000				559,000
J. TOTAL DIRECT COSTS (C through I)				559,000
K. INDIRECT COSTS				
L. TOTAL COSTS (J plus K)				
M. AMOUNT OF THIS AWARD (ROUNDED)				$ 559,000

REMARKS: Use extra sheet if necessary

Time is estimated on proposed footage drilled of 100 feet per day, i.e., 35 days to drill 3,500 feet. This includes time and cost for core drilling as directed.

SELF POTENTIAL STUDIES

C. T. Zablocki
U.S.G.S.

As was reported in the Quaterly Progress Report No. 4 for March 1 - June 30, 1974, a detailed self-potential survey of the lower east rift zone of Kilauea was planned in an effort to locate sites for the exploratory drilling program (pages 5-22). The rationale for making the detailed survey was based on the fact that extensive studies by the U.S. Geological Survey in many areas of Kilauea in recent years have indicated that measurements of self potentials appear to be the single most useful method for identifying anomalous thermal areas. Anomalies upwards to 1500 millivolts are related not only to recent extrusive activity at the summit and upper rift zones of Kilauea, but also within areas which have no obvious surface manifestations. These areas are also associated with low electrical resistivity anomalies. Further impetus for the detailed survey in Puna was provided by the previously reported detection of similar type anomalies in parts of the lower east rift zone which were associated with the eruptive activity of 1955 (see figures 1, 2, and 3 on p. 5-23, 24, and 25) of QPR No. 4.

A contour map of the self potential distribution resulting from this study is shown in fig. 1 . No anomalous areas were defined outside of this portion of the east rift zone and therefore are not shown. The contoured map was derived from measurements made at 100-meter intervals along available roads, trails, and in areas not inundated by recent flows.

Besides delineating the two previously reported anomalies in more detail (anomalies A and B shown on contour map), the survey identified only two other features of note. One is related to the anomaly just north of Puulena Crater. This small amplitude and narrow linear feature has an orientation (N40°W) which is transverse to the trend of the rift zone (anomaly C). The other feature (anomaly D), is also small in amplitude, but is broader and longer than anomaly C. Whereas A is obviously related to the still steaming vents of the 1955 eruption, the others have no surface indications of a heat source at depth. The fact that B and D are in line with the linear anomaly A to the west suggest that they also are related to the 1955 activity.

It is significant that only weak or no anomalies were detected over the other eruptive fissures of 1955 and 1960.

Source depth determinations made on these anomalies show them all to be near sea level. The shallow depths observed do not imply that magma is at that depth. If the mechanism generating the potentials is related to the movement of groundwater by convective forces, the depth to the very hot rocks or magma would probably be appreciably deeper than the depth at which the vertically rising water cools and diverges toward the horizontal (top of S.P. source). Collination of hydrothermal fluids by vertical gravitational forces would explain the clearly defined S.P. anomalies obtained at the summit of Kilauea which are much shallower than the depth to magma inferred from seismic and deformation studies.

In detail, the generation of large electrokinetic, or electrofiltration potentials do not require the mass velocity of the hydrothermal fluids to be large. All that is required to produce an emf is a net separation of charge in the pore waters which experience flow due to a differential pressure. Charge separation will occur if ions of the same polarity are preferentially absorbed on the grain surfaces of the rock, leaving the free liquid in the center of the pores enriched in ions with the opposite charge. Most rocks usually absorb anions so that the free moving water will contain excessive cations. Correspondingly, the resulting potentials will be positive in directions toward the high pressure side of the system. All anomalies defined in Kilauea have a positive polarity over the known or inferred hot zones and therefore anion absorbtion is assumed for these rocks as well. The associated low, or negative, anomalies noted on the contour map probably result from the change in direction of fluid flow, i.e., the descension of the cooler waters in the convective system. A conceptual model showing the pattern of the streamlines of fluid flows that might be involved above the heat source in the vicinity of a steaming fissure is shown in figure 2.

The positive anomalies of B and D do not have a large negative feature associated with them. It is possible that the descending fluids returning to the convective system (reverse direction of fluid flow) are at a greater depth. This could produce the more mono-polar nature of these anomalies.

The uniform positive gradient to the southeast can not result from a diffusion potential generated by the difference in salinity of the ocean waters and the groundwater. Notwithstanding a three decade difference in salinity, the resulting potential would be only about 40 millivolts.

In view of the fact that very weak anomalies were detected over other eruptive vents of 1955, it is difficult to explain the shallow, narrow, and linear feature, C, as caused by a near-surface intrusion. Repeated surveys over similar shaped features near the summit of Kilauea resulting from recent eruptions show a decrease in amplitude with time. This is explained by the rapid cooling of thin dikes. If however, the linear feature, C, represents a permeable vertical fracture which has hot water continuity with a heat source at depth, then it forces the constraint that the surrounding rocks below sea level would necessarily have to be fairly impervious. It is recognized that such a condition would most likely be needed for the existence of any viable hydrothermal resource in Kilauea.

The offset in the lower east rift zone in the vicinity of anomalies B and C together with the coincidences of the general epicentral area of recurrent shallow earthquake swarms (less than 5 km deep) in recent years make this area the most interesting in the search for geothermal energy. It is expected that a drill hole placed over anomaly B would encounter 100°C water at sea level and that the temperature will increase monotonically with depth. However, a hole placed too far from the top of the anomaly might encounter a near-surface temperature inversion as inferred in figure 2. If a potentially commercial reservoir is to be found, it will require a target depth much deeper and pervasive than that to be expected in the vicinity of a relatively thin dike. If we consider these short wave length S.P. features as possible leaks in an otherwise low permeable medium above a much larger heat source, then a deep hole located in this general area would be justified.

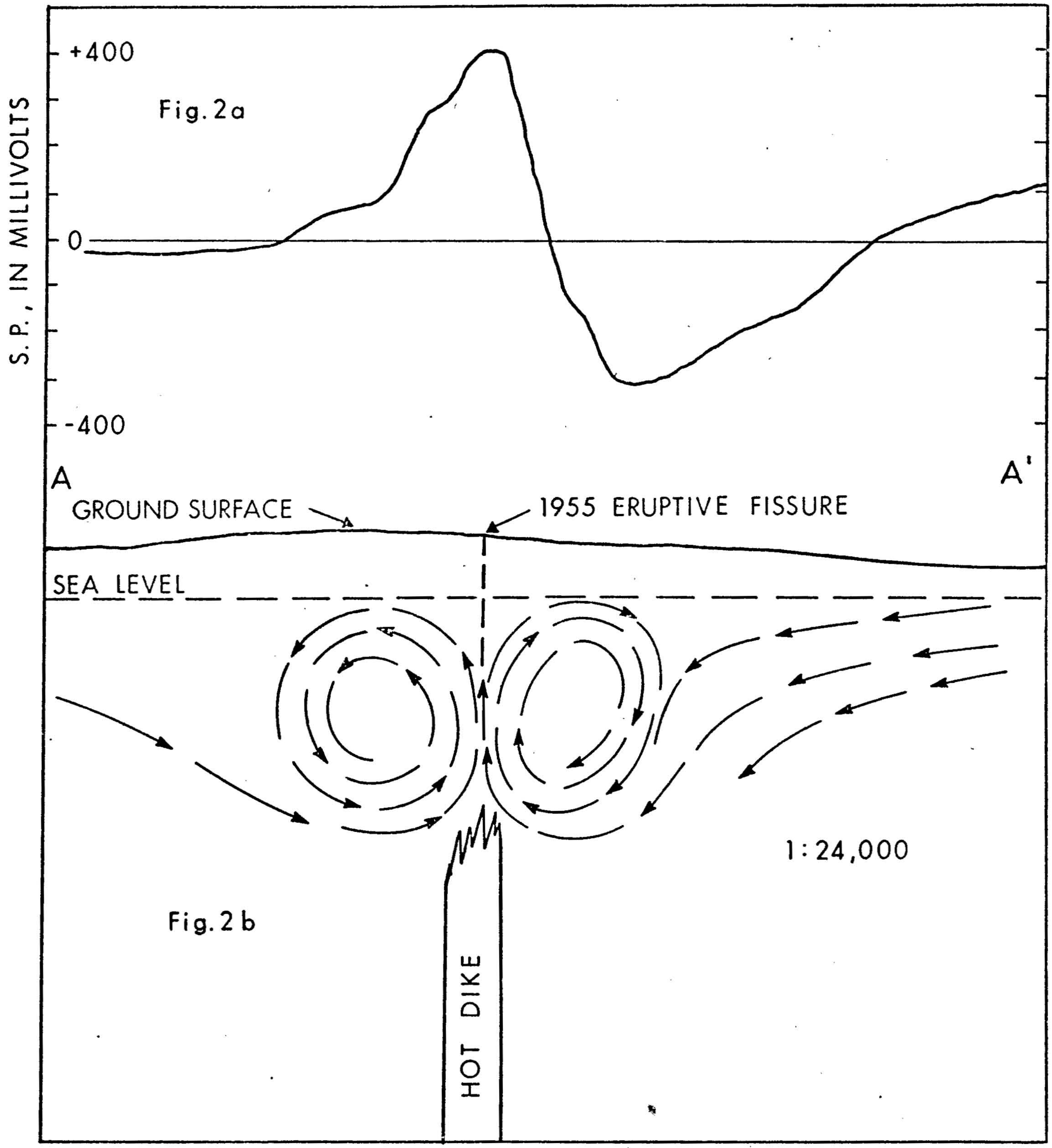
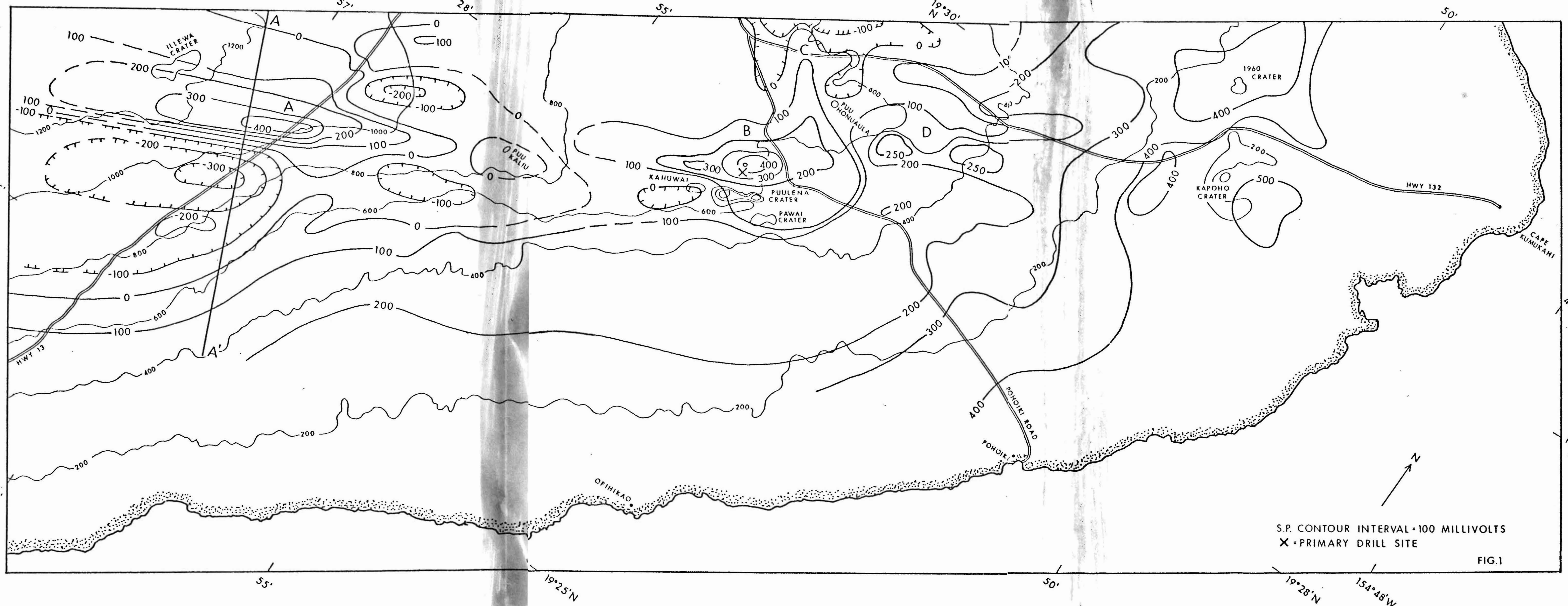


Figure 2a Self Potential Profile along Traverse A-A' shown in Figure 1.

Figure 2b Conceptual Model of Streamline flow patterns which would reconcile the potential distribution shown above



ILLEWA CRATER
PUU KALIU
KAHUWAI
PUULENA CRATER
PAWAI CRATER
PUU HONUAULA
1960 CRATER
KAPOHO CRATER
CAPE KUMUKAHI
HWY 13
HWY 132
POHOIKI ROAD
POHOIKI
OPIHIKAO
19°25' N
19°30' N
19°28' N
19°25'N
154°57' W
154°48'W
57'
55'
50'
48'
A
A'
B
C
D
S.P. CONTOUR INTERVAL = 100 MILLIVOLTS
X = PRIMARY DRILL SITE

FIG. 1