GL00947

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108-1295
TELEPHONE 801-524-3422

October 14, 1992

Mr. Bob Creed
Advanced Technologies Branch
Department of Energy-Idaho Field Office
785 DOE Place
Idaho Falls, ID 83401-1562

Dear Bob:

Enclosed for your information and records are several items relating to a technical review of report - AM/EP-ATB-92-247, "The Moana Geothermal System in Reno, Nevada: A Hydrologic, Geochemical, and Thermal Analysis" as requested in your letter of September 21.

Item A is a copy of Section 4.0 Technical Tasks (p. 2 of 2) from the Statement of Work for Grant No. DE-FG07-88ID12757 which describes in detail the original research program. Item B is a copy of an internal DOE/ID memo written to Elizabeth Bowhan by Ken Taylor and myself on September 6, 1990. This memo recommended changes in the Statement of Work which became necessary as various difficulties became apparent during the study. I understand that these recommendations were formalized as a Contract Modification at DOE/ID, but I do not have a copy of the finalized Contract Modification.

Item C is a copy of my letter of February 21, 1991 with enclosed technical and editorial review comments for the Draft Final Report. My subsequent review of the Final Report, which I have just repeated, indicates that all substantial technical and editorial comments were satisfactorily responded to when revisions were completed.

A short, stand-alone review of the Final Report is also enclosed. Although the principal objective of the study, a calibrated and verified numerical model of the Moana geothermal reservoir, was not possible, the DRI team completed a very nice study of the reservoir. They evaluated 188 wells which produce from the system and monitored 26 selected wells for a 13-month period for water level and temperature. They documented substantial draw-down in the central portion of the system, formed a conceptual model of the system, and identified additional data needed to complete a detailed numerical model.

In the course of working with individual home owners, water producers, drillers, and regulatory agencies, the DRI team raised the awareness of the geothermal reservoir and potential problems of uncoordinated development. Appropriately, the results of this study were presented at the 1991 GRC Annual Meeting in Reno, by Elizabeth Jacobson, Principal Investigator.

Please contact me if you require additional information.

Sincerely,

Howard

Howard P. Ross
Project Manager

HR/mt
Enclosure

ITEM A.

4.0 TECHNICAL TASKS

The following tasks will be accomplished under this grant.

4.1 Collect and assess the quality of all relevant existing data including hydraulic data, thermal data, well data, geologic data, hydrochemical data and hydrologic data.

4.2 Collect new data on the Moana geothermal system for a period of 13 months. Perform weekly measurements of water levels and temperatures in selected wells. Design and conduct aquifer tests to characterize storage and fluid conductive properties of the reservoir and the nature of the boundaries. Determine thermal gradients in wells, and chemical analyses of well fluids.

4.3 Complete calibration and verification of a numerical model simulating the Moana geothermal reservoir using the data from Tasks 4.1 and 4.2. Verify the accuracy of the model under both steady state and transient conditions. The USGS numerical model program SUTRA will be used for the modeling and simulation of the reservoir.

4.4 Perform reservoir simulations for a variety of development scenarios using the calibrated and verified SUTRA model. The simulations will show the effects of temperature distributions due to pumping and injection; plumes of lower temperature water due to injection; solute concentrations and distributions due to pumping; high solute concentration plumes due to reinjection; and areas of decreased water levels due to groundwater withdrawal.

4.5 Complete the documentation of all new resource data, a description of the Moana reservoir model and the results and interpretation of the model simulations. Prepare a user's manual for the Moana reservoir model and deliver to the three state regulatory agencies and to interested parties.

5.0 REPORTS, DATA, AND OTHER DELIVERABLES

5.1 Reports will be due as indicated on the Federal Assistance Reporting Checklist and the Report Distribution List.

5.2 A detailed final technical report will be prepared which will document all inventoried and new resource data, and will describe the Moana reservoir model and the results and interpretation of the model simulations. A user's manual for the Moana reservoir model will be included as an appendix. Any new software developed which is necessary for the execution of the reservoir model will be described and a listing included. A draft final report will be submitted to DOE/ID for review and comment not less than 45 days prior to the scheduled delivery of the final report.

6.0 SPECIAL CONSIDERATIONS

None.

vp/Thorne/1261

ITEM B.

To: Elizabeth Bowhan, DOE-ID
From: Ken Taylor, DOE-ID KT.

Date: September 6, 1990

Subject: University of Nevada System (DRI) Grant #DE-FG07-88ID12757

Both myself and Howard Ross, UURI have reviewed the letter from Elizabeth Jacobson, DRI to yourself dated August 23, 1990. This letter requests both changes to the Grant statement of work and a no cost time extension, (NCTE) from November 30, 1990 to February 28, 1991. The changes, in large part, are due to the new principle investigator's interpretation of the statement of work and limitations in the computer program and existing data base. These changes to the statement of work and the NCTE are acceptable. The individual changes are discussed below.

A minor change in the scope of work reflects limitations in the computer program and in the available data base to be used in the numerical simulation of the Moana geothermal system. This change results in no reduction of effort, but a minor reduction in precision of the results, which is unavoidable.

Changes requested in Task 4.2 reflect a change from weekly to monthly monitoring of wells as noted in the DRI quarterly report dated January 27, 1989. This does not detract from the quality of the data base. The cost savings for this reduction are minimal as graduate students are performing the work. These savings will be used for other tasks within the project.

Changes requested in Task 4.3 substitute the word "evaluate" for "verify" with regard to the reservoir model. It is physically impossible to "verify" the reservoir model, so this wording is more appropriate. There is no change in task effort or cost.

Changes requested in Task 4.4 reflect limitations in the USGS SUTRA modeling program which have become apparent during this study, i.e. the program cannot simultaneously model fluid and heat transport, and solute transport. The requested change recognizes that the solute transport (chemical information) data base is limited and will be evaluated independently. This actually complicates the study but the grantee has accepted this as part of the overall work scope. This change is acceptable.

If there are any questions, please contact me at extension 6-9063.

ITEM C.

UNIVERSITY OF UTAH RESEARCH INSTITUTE

UURI

EARTH SCIENCE LABORATORY
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108—1295
TELEPHONE 801-524-3422

February 21, 1991

Dr. Elizabeth Jacobson
Desert Research Institute
University of Nevada System
P. O. Box 60220
Reno, NV 89506-0220

Dear Elizabeth:

Thank you for the opportunity to review your draft final report "The Moana Geothermal System in Reno, Nevada: A Hydrologic, Geochemical, and Thermal Analysis". I have completed a preliminary review and find the report to be quite well written and generally free from errors. The illustrations are good, the data are well presented, the conceptual model, data analysis, and development of analysis of fluid chemistry to monitor temperature changes all represent good work.

I expect that you are a little disappointed that you were unable to conduct and present an in depth numerical model study with the available data. It was our hope also. It seems that you have done the best to be expected with the limitations you enumerate.

I have asked Joe Moore, our Chief Geochemist, to review the section on fluid chemistry and temperature monitoring, and hope to have his comments tomorrow. Marshall Reed has only had a few minutes to look at the report so far, but appreciates that you hope to complete any revisions as soon as possible.

I have enclosed one page of Comments/Corrections for you to consider and begin changes as appropriate. With luck you won't have to make changes in pagination, if that is important to saving time.

I tried to call you earlier but had no answer. In the interest of time I will FAX these comments, so you can review them and call me for clarification. I will contact you with other comments as I receive them.

Sincerely,

Howard

Howard Ross
Project Manager, SCP

H.P. Ross
Feb. 21, 1991

UNLV-DRI MOANAGEOTHERMAL STUDY
REVIEW COMMENTS ON DRAFT FINAL REPORT

Page	Comment/Correction
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ii	Abstract- alternate wording,
iii	Acknowledgements, para. 3, 1 7- ~~the~~ to
v	para. 3, 1.7- ~~Thus~~ However
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52	Fig.34- there is no plot point for nonthermal water- were all values below detection limit? if so show this.
73	para.2- refers to model of Bateman and Scheibach, Fig.2, but Fig. 2 caption credits Wright and Culver? Can you clarify in discussion?
78	It appears tha a modeling grid had been established in preparation for numerical modeling- was any modeling attempted? Are any model attempts described? Where are these discussed?
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The main shortcomming of the report that I can identify is the lack of a geologic map which locates bedrock units and mapped or inferred fault locations. The complex geology and importance of faults as controls for fluid conduits, etc. are discussed on pgs. 2,4,5,73,74,75,77 and elsewhere. If most of the area is Quaternary alluvium cover, it would at least be appropriate to have the inferred fault locations shown on drill hole, hydraulic head, and temperature maps, such as Fig.51. Faults should be named if appropriate. Also, there is no mention of the nearby, possibly related Steamboat Springs geothermal system and possible common controls and interrelationships. Please discuss these.

UNLV-DRI MOANA GEOTHERMAL STUDY

REVIEW COMMENTS ON DRAFT FINAL REPORT

Supplemental Comments by UURI Geochemists

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58	first para- contour plots showing locations of wells and chemistry and temperature would be interesting and instructive, and would enhance the report. They could help confirm your hypotheses.
70	It would be useful to calculate geothermometer temperatures- try SiO2, K-Mg-Na , Na-K-Ca-Mg: examine any trends. The lack of geothermometer calculations in a study such as this is surprising!

TECHNICAL REVIEW

THE MOANA GEOTHERMAL SYSTEM IN RENO, NEVADA: A HYDROLOGIC, GEOCHEMICAL, AND THERMAL ANALYSIS

by

Elizabeth A. Jacobson and Jeffrey W. Johnston

The subject report describes a 30 month study of the Moana geothermal system, located near Reno, Nevada. The study included historical data gathering, field work and new data acquisition, interpretation and the development of a conceptual model of the geothermal reservoir, attempts at numerical modeling, and reporting. The ultimate objective of the study, to construct and calibrate a numerical model of the Moana geothermal system to simulate the reservoir for a number of development scenarios for use by developers and regulators, was not achieved.

The report provides a good summary of the historical development of the Moana geothermal system and the geologic controls and previous geoscientific studies. It presents a database which includes the location of 188 wells which use the Moana resource, and detailed construction, water level, temperature and chemical data for 26 carefully selected wells which were monitored for a 13-month period. The report describes in some detail the difficulties of obtaining accurate temperature data in active wells with downhole heat exchangers, pumps, and other hardware.

Groundwater chemistry of the geothermal system is discussed in some detail. Groundwater chemistry indicates a mixing of thermal and nonthermal water, in agreement with the isotopic results of earlier workers. The authors describe a scheme for indicating relative temperature changes in the geothermal reservoir, at a given well location, based on the concentration with temperature relationships for various soluble elements, such as boron and chloride.

The authors note a decline of water level with time in the central portion of the study area where there is a high density of wells with pumps, and a decrease in water level since 1984 in a monitoring well located at Manzanita Park, down gradient of the main resource area. The monitoring well at Horseman's Park, upgradient of the main resource area shows a water level increase of 5 ft between 1984 and 1989.

The final report presents a conceptual model for the geothermal system, and a finite-element grid for modeling of the Moana geothermal area. The authors identify several unknown parameters (hydraulic and thermal conductivities of the layer between the two aquifers; spatial distribution of the thickness of this layer; hydraulic heads and temperatures in the overlying unconfined aquifer; etc.) which are not sufficiently known at present to constrain the numerical model. One important result of the interpretation expressed in the report, is the probably increased leakage of the upper, cold water aquifer into the moderate temperature aquifer in response to increased production from the latter. This will result in a temperature decline of the mixed-water reservoir and additional stress on the reservoir in response to heating needs.

The report is an excellent documentation of the available data and the results of the study. The conduct of the field work and well monitoring, and presentation of results at the 1991 Geothermal Resources Council meeting at Reno called attention to problems which will result from further uncoordinated production from the reservoir. However, additional data gathering and the completion of numerical modeling which will require considerable funding, are required before state regulators can act decisively to guarantee the long-term productivity of the Moana geothermal reservoir.

Howard P. Ross
October 14, 1992

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February 21, 1991

Dr. Elizabeth Jacobson
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University of Nevada System
P. O. Box 60220
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To: Elizabeth Bowhan, DOE-ID
From: Ken Taylor, DOE-ID K.T.

Date: September 6, 1990

Subject: University of Nevada System (DRI) Grant #DE-FG07-88ID12757

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If there are any questions, please contact me at extension 6-9063.

DOE F 4600.1
(7-81)

U.S. DEPARTMENT OF ENERGY
NOTICE OF FINANCIAL ASSISTANCE AWARD
(See Instructions on Reverse)

Budget Period
Project Period
SOW says 22 mo.

Under the authority of Public Law PL 93-410 and subject to legislation, regulations and policies applicable to *(cite legislative program title)*:
Geothermal Energy Research, Development, and Demonstration Act of 1974

1. PROJECT TITLE
Evaluation and Simulation of Moana Geothermal System

2. INSTRUMENT TYPE
☒ GRANT ☐ COOPERATIVE AGREEMENT

3. RECIPIENT *(Name, address, zip code, area code and telephone no.)*
Desert Research Institute
University of Nevada System
P.O. Box 60220, Reno, NV 89506-0220

4. INSTRUMENT NO.
DE-FG07-88ID12757

5. AMENDMENT NO.

6. BUDGET PERIOD
FROM: 7/1/88 THRU: 6/30/89 ?

7. PROJECT PERIOD
FROM: 7/1/88 THRU: 4/30/90

8. RECIPIENT PROJECT DIRECTOR *(Name and telephone No.)*
Michael E. Campana (702) 673-7392

9. RECIPIENT BUSINESS OFFICER *(Name and telephone No.)*
Carla Cosens (702) 673-7366

10. TYPE OF AWARD
☒ NEW ☐ CONTINUATION ☐ RENEWAL
☐ REVISION ☐ SUPPLEMENT

11. DOE PROJECT OFFICER *(Name, address, zip code, telephone No.)*
Kenneth J. Taylor (208) 526-9063
U.S. DOE, Idaho Operations Office
785 DOE Place, Idaho Falls, Idaho 83402

12. ADMINISTERED FOR DOE BY *(Name, address, zip code, telephone No.)*
Trudy A. Thorne (208) 526-9519
U.S. Department of Energy
Idaho Operations Office
785 DOE Place
Idaho Falls, Idaho 83402

13. RECIPIENT TYPE
☐ STATE GOV'T ☐ INDIAN TRIBAL GOV'T ☐ HOSPITAL ☐ FOR PROFIT ORGANIZATION ☐ INDIVIDUAL
☐ LOCAL GOV'T ☒ INSTITUTION OF HIGHER EDUCATION ☐ OTHER NONPROFIT ORGANIZATION ☐ C ☐ P ☐ SP ☐ OTHER *(Specify)*

14. ACCOUNTING AND APPROPRIATIONS DATA

a. Appropriation Symbol	b. B & R Number	c. FT/AFP/OC	d. CFA Number
89X0224.91	AM1510000	410	

15. EMPLOYER I.D. NUMBER/SSN

16. BUDGET AND FUNDING INFORMATION

a. CURRENT BUDGET PERIOD INFORMATION

(1) DOE Funds Obligated This Action	$ 140,639
(2) DOE Funds Authorized for Carry Over	$ -0-
(3) DOE Funds Previously Obligated in this Budget Period	$ -0-
(4) DOE Share of Total Approved Budget	$ 140,639
(5) Recipient Share of Total Approved Budget	$ 15,627
(6) Total Approved Budget	$ 156,266

b. CUMULATIVE DOE OBLIGATIONS

(1) This Budget Period *[Total of lines a.(1) and a.(3)]*	$ 140,639
(2) Prior Budget Periods	$ -0-
(3) Project Period to Date *[Total of lines b. (1) and b. (2)]*	$ 140,639

17. TOTAL ESTIMATED COST OF PROJECT $ 156,266
(This is the current estimated cost of the project. It is not a promise to award nor an authorization to expend funds in this amount.)

18. AWARD/AGREEMENT TERMS AND CONDITIONS

This award/agreement consists of this form plus the following:

a. Special terms and conditions (if grant) or schedule, general provisions, special provisions (if cooperative agreement)

b. Applicable program regulations *(specify)* ______ *(Date)* ______

c. DOE Assistance Regulations, 10 CFR Part 600, as amended, Subparts A and ☒ B (Grants) or ☐ C (Cooperative Agreements).

d. Application/proposal dated June 18, 1987, ☐ as submitted ☒ with changes as negotiated

19. REMARKS This Grant Consists of this NFAA (DOE Form 4600.1), Part I - Budget Plan; Part II - Special Conditions; Part III - General Conditions; Part IV - Statement of Work; Part V - Reporting Requirements. DOE Financial Assistance Rules (10 CFR Part 600), OMB Circular A-110 and OMB Circular A-21 are hereby incorporated by reference.

20. EVIDENCE OF RECIPIENT ACCEPTANCE
[signature] 6/6/88
(Signature of Authorized Recipient Official) *(Date)*
Dale F. Schulke
(Name)
Vice President for Finance/Admin.
(Title)

21. AWARDED BY
[signature] 5/26/88
(Signature) *(Date)*
J. P. Anderson, Contracting Officer
(Name)
Chief, R&D Contracts Branch
(Title)

f. Applicable Credits - The Grantee agrees that any refunds, rebates, credits, or other amounts (including any interest thereon) accruing to or received by the Grantee or any assignee under this grant shall be paid by the Grantee to the Government, to the extent that they are properly allocable to costs for which the Grantee has been reimbursed by the Government under this grant. Reasonable expenses incurred by the Grantee for the purpose of securing such refund, rebates, credits, or other amounts shall be allowable costs hereunder when approved by the Contracting Officer.

g. Audit Adjustments - The Contracting Officer may have invoices or vouchers and statements of cost submitted under this grant audited at any time prior to the end of the required retention period for the grant records. Each payment made shall be subject to reduction for amounts included in the related invoice or voucher which are found by the Contracting Officer, on the basis of audit, not to constitute allowable cost. If a final audit of costs has not been performed prior to closeout of the grant, DOE or its successor agency, shall have the right to recover an appropriate amount after fully considering the recommendations on disallowed costs resulting from the final audit when conducted.

h. Cognizant Office - Invoices should be sent to the individual designated in Block 12. of the Notice of Financial Assistance Award Form (NFAA). In addition to the initial supply of forms made available with this award, appropriate payment forms and instructions will be provided by this office upon request.

2. Budget Flexibility and Limitation of DOE Liability

a. Under the terms of this award, grantee may obligate up to 110% of the amount awarded by DOE for a budget period, during that period, without prior authorization by DOE. Obligations in excess of 110% of the amount awarded by DOE require prior DOE authorization. (A prior approval made in accordance with the provisions of paragraph b. of this clause would constitute such prior approval.) Such authorized grantee obligations in excess of the amount awarded by DOE for a budget period shall be funded from unobligated funds remaining from the prior budget period to the extent they are available; or such obligations may be incurred at grantee's own risk, subject to the following conditions:

(1) If grantee receives a continuation or renewal award, the amount obligated in excess of 100% may be charged against the subsequent continuation or renewal award to the extent not funded from any unobligated balance from an earlier budget period.

Grant No. DE-FG07-88ID12757
Part I - Budget Plan

FEDERAL ASSISTANCE BUDGET INFORMATION FORM

FORM EIA-459C
(10-80)

FORM APPROVED
OMB No. 1900-0127

1. Program/Project Identification No. DE-FG07-88ID12757	2. Program/Project Title Moana Geothermal System
3. Name and Address Desert Research Institute, University of Nevada System P.O. Box 60220, Reno, NV 89506	4. Program/Project Start Date July 1, 1988 5. Completion Date April 30, 1990

SECTION A - BUDGET SUMMARY

Grant Program, Function or Activity (a)	Federal Catalog No. (b)	Estimated Unobligated Funds: Federal (c)	Estimated Unobligated Funds: Non-Federal (d)	New or Revised Budget: Federal (e)	New or Revised Budget: Non-Federal (f)	New or Revised Budget: Total (g)
1. 12693	81.087	$	$	$	$	$
2. First Year				81,827	9,092	90,919
3. Second Year				58,812	6,535	65,347
4.						
5. TOTALS		$	$	$	$	$

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	Grant Program, Function or Activity: 1st Year (1) DOE	1st Year (2) DRI	2nd Year (3) DOE	2nd Year (4) DRI	Total (5)
a. Personnel	$ 27,047	$3,005	$18,194	$ 2,022	$50,268
b. Fringe Benefits (30.25%)	4,508	500	3,904	434	9,346
c. Travel	1,158	129	609	68	1,964
d. Equipment					
e. Supplies	1,788	199	754	84	2,825
f. Contractual					
g. Construction					
h. Other	12,258	1,362	10,146	1,126	24,892
i. Total Direct Charges	46,759	5,195	33,607	3,734	89,295
j. Indirect Charges (75%)	35,068	3,897	25,205	2,801	66,971
k. TOTALS	$ 81,827	$ 9,092	$58,812	$ 6,535	156,266
7. Program Income	$	$	$	$	$

NOTE: This Grant is for a twenty two month period at a total estimated DOE cost of $140,639 and total estimated Grantee cost of $15,627 for a total of $156,266.

This will be funded as follows:

First Year:	DOE	-	$81,827	Grantee	-	$9,092
Second Year:	DOE	-	58,812	Grantee	-	6,535
			$140,639			$15,627

Special Terms and Conditions for Research Grants

The requirements of this attachment take precedence over all other requirements of this grant found in regulations, the general terms and conditions, DOE orders, etc. except requirements of statutory law. Any apparent contradiction of statutory law stated herein should be presumed to be in error until the Grantee has sought and received clarification from the Contracting Officer, whose signature appears on the face page of this award.

1. Payments and Cost-Share

   a. The Grantee may request advance payment of cost to be incurred. Such requests should not exceed the expected outlays by the Grantee in the succeeding 30-day period.

   b. Cost-Share Arrangement - The cost-share will be in accordance with Part I - Budget Plan. Invoices must include in-kind contributions and DOE's reimbursed costs. To be an invoiced cost, a cash or in-kind contribution must be allowable under the terms and conditions of the award and meet the applicable cost principle tests of allowability in 10 CFR 600.103.

      Allowable costs incurred under this grant will be cost-shared on the basis of 90% DOE and 10% Grantee.

   c. Payments to the Grantee shall equal the Federal share of actual allowable costs of performance of this grant, provided however, and notwithstanding any other provision of this grant, that the Government's monetary liability under this grant shall not exceed the Government share of the total approved budget or an amount equal to the Federal share of actual allowable costs, whichever is less. The Grantee shall be obligated to perform under this grant throughout the agreed-upon period of performance, and to bear all costs which DOE has not agreed to pay. However, the Grantee shall have the right to cease to perform when or after the Federal share of actual allowable costs equals or exceeds the Government share of the total approved budget and if prior written notice to that effect has been provided to DOE.

   d. The Government obligations may be increased unilaterally by DOE by written notice to the Grantee and may be increased or decreased by written agreement of the parties.

   e. Upon termination or expiration of the total period of performance, the Grantee shall promptly refund to DOE (or make such disposition as DOE may in writing direct) any sums paid by DOE to the Grantee under this grant in excess of the cumulative Government allowable cost incurred in performance under the grant.

f. Applicable Credits - The Grantee agrees that any refunds, rebates, credits, or other amounts (including any interest thereon) accruing to or received by the Grantee or any assignee under this grant shall be paid by the Grantee to the Government, to the extent that they are properly allocable to costs for which the Grantee has been reimbursed by the Government under this grant. Reasonable expenses incurred by the Grantee for the purpose of securing such refund, rebates, credits, or other amounts shall be allowable costs hereunder when approved by the Contracting Officer.

g. Audit Adjustments - The Contracting Officer may have invoices or vouchers and statements of cost submitted under this grant audited at any time prior to the end of the required retention period for the grant records. Each payment made shall be subject to reduction for amounts included in the related invoice or voucher which are found by the Contracting Officer, on the basis of audit, not to constitute allowable cost. If a final audit of costs has not been performed prior to closeout of the grant, DOE or its successor agency, shall have the right to recover an appropriate amount after fully considering the recommendations on disallowed costs resulting from the final audit when conducted.

h. Cognizant Office - Invoices should be sent to the individual designated in Block 12. of the Notice of Financial Assistance Award Form (NFAA). In addition to the initial supply of forms made available with this award, appropriate payment forms and instructions will be provided by this office upon request.

2. Budget Flexibility and Limitation of DOE Liability

a. Under the terms of this award, grantee may obligate up to 110% of the amount awarded by DOE for a budget period, during that period, without prior authorization by DOE. Obligations in excess of 110% of the amount awarded by DOE require prior DOE authorization. (A prior approval made in accordance with the provisions of paragraph b. of this clause would constitute such prior approval.) Such authorized grantee obligations in excess of the amount awarded by DOE for a budget period shall be funded from unobligated funds remaining from the prior budget period to the extent they are available; or such obligations may be incurred at grantee's own risk, subject to the following conditions:

(1) If grantee receives a continuation or renewal award, the amount obligated in excess of 100% may be charged against the subsequent continuation or renewal award to the extent not funded from any unobligated balance from an earlier budget period.

(2) Even if prior authorization required by this paragraph has been obtained, grantee shall not be entitled to reimbursement, or have any claim against DOE, for any amount obligated by grantee in excess of the total funds obligated by DOE, if a continuation or renewal award is not made.

b. When the funds remaining unobligated by the grantee in any given budget period are 10% or less of the amount awarded by DOE for the subsequent budget period, grantee may use the unobligated funds during the subsequent budget period to pay for costs (1) budgeted for in either budget period and (2) subject to any applicable prior approval requirements. If funds remaining unobligated by the grantee at the end of a budget period exceed 10% of the amount awarded for the subsequent budget period, use of the amount in excess of 10% must receive the prior approval of the Contracting Office.

c. Nothing in paragraphs a. or b. of this article shall in any way require DOE to increase the total obligated for the project period or to make any additional supplemental, continuation, renewal, or other award for the same or any other purpose.

3. <u>Reporting Program Technical Performance</u>

a. <u>Copies</u>. Copies of reports and all other related data and information generated under this grant shall be submitted in accordance with the attached Federal Assistance Reporting Checklist (DOE Form EIA-459A).

b. <u>Publication of Results</u>. The Grantee may publish the results of its work. However, publications and reports prepared under this grant shall contain the following acknowledgment statement, "This (material) was prepared with the support of the U.S. Department of Energy (DOE) Grant No. DE-FG07-88ID12757. However, any opinions, findings, conclusions, or recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of DOE."

c. <u>Reporting Requirements</u>. The Federal assistance recipient shall prepare and submit (postage prepaid) the plans and reports indicated on the Federal Assistance Reporting Distribution List. Preparation of the specified plans and reports shall be in accordance with DOE Order 1332.2. The level of detail the recipient provides in the plans and reports shall be commensurate with the scope and complexity of the task and shall be as delineated in Block 4 - Reporting Requirements and Block 5 - Special Instructions.

All reports delivered to DOE shall be the sole property of DOE. The Grantee shall not claim that any report contains any trade secrets or commercial or financial information deemed by the Grantee to be privileged or confidential, or that the Grantee has any proprietary interest in any report.

4. Designated Key Personnel

The following individual is designated key personnel in accordance with General Condition No. 14:

Michael E. Campana

5. Project Completion Date

The project completion date identified in Block 7. of the Notice of Financial Assistance Award includes an additional 90 days for completion of the final report. All R&D effort must be completed 90 days prior to the project completion date. Only costs associated with preparation of the final report will be allowed during the 90 days prior to the project completion date.

6. Technical Data

Except for technical data contained in pages N/A of the recipient's application, dated N/A, which are asserted by the Grantee as being proprietary data, it is agreed that as a condition of this award, and notwithstanding the provisions of any notice appearing on the application, the Government shall have the right to use, duplicate, disclose and have others do so for any purpose whatsoever the technical data not identified in the above blanks contained in the application upon which this award is based.

7. Prior Approval

The following actions or costs specified in the application require prior approval of DOE and are specifically disapproved in accordance with General Condition No. 3:

None

8. General Procurement Prior Approval

Article 17 of the General Terms and Conditions for Research Grants is hereby revoked. Grantee must receive prior approval from DOE before entering into any sole source contract or a contract where only one bid or proposal is received, when the value of the contract in the aggregate is expected to exceed $25,000.

9. Patent Clauses

The following patent clauses and technical data requirements are applicable to this grant award:

600.118(b)(1) "Patent Rights (Small Business Firm or Nonprofit Organization)"

600.118(b)(3) "Rights in Technical Data (Short Form)"

600.118(b)(5) "Authorization and Consent"

600.118(b)(6) "Notice and Assistance"

600.118(c) "Reporting of Royalties"

10. Title to Equipment

a. Title to the following items of equipment shall vest with the Grantee upon completion of this grant:

None

b. Title to the following items of equipment shall vest with the Government at the end of the grant project period:

None

11. Annual Budget Review

The Budget Plan included in this grant is subject to annual review by DOE. The Grantee shall submit to the DOE Contracting Officer: 1) the status of progress on the research effort; 2) the actual costs to date; 3) the estimated cost to complete the research effort being supported; and 4) any proposed charges to the current budget plan. This information shall be submitted annually in the same level of detail as the original proposal. The annual submission date shall be within 15 days of the day identified as the start date of the budget period in Block 6. of the Notice of Financial Assistance Award. Items 1) and 2) above may be provided as part of the Financial Assistance Management Summary Report (FAMSR) if the annual submission date and the normal FAMSR due date coincide.

12. Advance Travel Agreement

It has been agreed by both parties that payment for a privately-owned conveyance used for official purposes shall be made on the basis of the actual travel performed computed at the mileage rate not to exceed $.21/mile.

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General Terms and Conditions for Research Grants

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General Terms and Conditions for Research Grants

1. Explanation

These general terms and conditions do not restate all the provisions of applicable statutes and regulations nor do they represent an exhaustive listing of all requirements applicable to this grant. Rather they highlight and are consistent with those requirements which are especially pertinent to research grants in general. They are being emphasized by inclusion here either because they are invoked with high frequency, their violation is a matter of especially serious concern (e.g., use of human subjects), and/or they have been restated in the research context to be more easily understood by the research community.

In addition to these general terms and conditions, the grantee must comply with all governing requirements, including those identified in Block 18 of the Notice of Financial Assistance Award and those included in the Special Terms and Conditions attached to this grant award.

2. Grantee Adherence to Grant Terms and Conditions

The grantee's signature on the application and on the Notice of Financial Assistance Award signifies the grantee's agreement to the terms and conditions of award. Should the grantee believe modification of any of the terms and conditions of this award is necessary, an authorized official of the grantee organization or, in the case of an individual, the grantee, must submit a written request on its own behalf or on behalf of any subgrant recipient or applicant to the Contracting Officer named on the face page of this award.

Following this procedure is very important because many of the terms and conditions of this grant are required by statute and must be enforced by the Department of Energy.

3. Definitions

Principal Investigator

As used herein, the scientist or other programmatic expert named in Block 8 of the Notice of Financial Assistance Award designated by the grantee organization to direct the scientific/technical efforts being supported (also called program director or project director/leader).

Prior Approval

A statement in writing, signed by the DOE Contracting Officer, that a cost may be incurred or an action may be taken. The approval may take the form of a letter or of a revision to the grant. If actions or costs requiring prior approval are specified in the application and are not expressly disapproved by DOE in the attached Special Terms and Conditions, the award of the grant constitutes such prior approval.

4. Authorized Grantee Signatures for Prior Approval Requests

All requests for prior approval must be signed by an individual who is authorized to act for the grantee organization. The signature of the Principal Investigator (unless also a corporate officer or otherwise authorized) is insufficient to obtain action on a prior approval request, although countersignature by the Principal Investigator is not discouraged. Requests for budget revisions shall be made on the same budget format as used in applying for this grant and must be supported by a narrative justification. Other prior approval requests may be made by letter. Prior approval requests should be addressed to the Contracting Officer named on the face page of this award.

5. Allowable Costs/Applicable Cost Principles

In accordance with the applicable cost principles cited below and up to the amount shown on the face page of this award for the total approved budget for the current budget period (line 16.a.(6)), the allowable costs of this grant shall consist of the actual allowable direct costs incident to performance of this project plus the allocable portion of the allowable indirect costs, if any, of the organization less applicable credits.

The allowability of costs for work performed under this grant and any subsequent subaward will be determined in accordance with the Federal cost principles applicable to the grantee or subrecipient in effect on the date of award or, for any subaward, in effect as of the date of that subaward, except as modified by other provisions of this grant or the subaward.

The Federal cost principles applicable to specific types of grantees and subrecipients are:

1. Institutions of Higher Education. OMB Circular A-21, Cost Principles Applicable to Grants, Contracts and Other Agreements with Institutions of Higher Education, is applicable to both public and private colleges and universities.

2. State and local governments and Indian tribal governments. OMB Circular A-87, Cost Principles Applicable to Grants, Contracts and other Agreements With State and Local Governments, is applicable to state, local, and Indian tribal governments (and shall also be used to the extent appropriate for foreign governments).

3. Hospitals. 4S CFR Part 74, Appendix E, Principles for Determining Costs Applicable to Research and Development under Grants and Contracts with Hospitals, applies to nonprofit and for-profit hospitals.

4. Other nonprofit organizations and individuals. OMB Circular A-122, Cost Principles Applicable to Grants, Contracts, and other Agreements with Nonprofit Organizations, applies to nonprofit organizations and individuals except for nonprofits specifically exempted by the terms of the circular or those nonprofits covered by the cost principles cited in items 1.- 3. above.

5. Commercial firms and certain nonprofit organizations. 48 CFR Subpart 31.2, Contracts with Commercial Organizations, as supplemented by 48 CFR Subpart 931.2, applies to those nonprofit organizations not covered by OMB Circular A-122, as specified by the terms of that circular, and to all commercial organizations other than those covered by the cost principles in item 3. above.

6. Payment

Payments under this award will be made by an advance payment method unless DOE determines that the grantee's financial management system does not meet the requirements of 10 CFR 600.109 or the grantee has not maintained, or demonstrated the willingness and ability to maintain, procedures that will minimize the time elapsing between transfer of funds from the U.S. Treasury and their disbursement for grant-related purposes.

The appropriate advance payment method or the reimbursement method and the cognizant finance office are specified in the attached Special Terms and Conditions.

Advances by the grantee to subgrantee and contractor organizations must conform substantially to the same standards of timing and amount that govern advances made by the Federal Government to the grantee. Excess cash advances erroneously withdrawn from the U.S. Treasury shall be promptly refunded to DOE unless the funds will be disbursed within seven calendar days or the amount is less than $10,000 and will be disbursed within 30 calendar days.

Interest earned on advance payments to other than state governments or their subgrantees shall be reported on the Report of Federal Cash Transactions (SF-272) and promptly remitted to the cognizant finance office (unless otherwise specified in the attached Special Terms and Conditions) by check payable to the Department of Energy.

7. Preaward Costs

Costs incurred prior to the beginning date of a new or renewal award are allowable only if they were approved in writing, prior to incurrence, by a DOE Contracting Officer. (Note - this provision does not apply to such bid and proposal costs as may be recovered through an indirect cost rate negotiated in accordance with the applicable Federal cost principles.)

8. Reporting Requirements

Attached to this grant award is EIA 459A, a checklist of the reports required under this grant.

The grantee shall submit a technical progress report (also called a performance report) as part of any application for continuation or renewal of DOE grant support. This report shall be in lieu of a separate annual performance report. Upon completion or termination of the project, the final technical report shall be prepared in accordance with the applicable program rule cited on the face page of this award or, in the absence of such program rule coverage, with the technical reporting format specified in the Uniform Reporting System for Federal Assistance (Grants and Cooperative Agreements) (DOE/MA-001).

The grantee shall submit an annual Financial Status Report (SF-269) within 90 days after the close of the budget period shown on the face page of this award. The grantee shall submit a final Financial Status Report within 90 days after the completion or termination of the project period shown on the face page of this award unless the project period is extended. In the latter case, the report for the last budget period of the existing project period shall be considered an annual report.

Instructions concerning reports to be submitted in conjunction with payment under this award are specified in the attached Special Terms and Conditions.

9. Cost-Sharing

Any cost-sharing as shown on the face page of this award shall defray allowable costs of the project only. Allowability of such costs shall be determined in accordance with the statutes, regulations, applicable cost principles, and other terms and conditions governing this award.

Cost-sharing contributions may be in the form of direct or indirect costs, including cash or in-kind contributions, incurred by the grantee, its subgrantees, or contractors. The cost sharing may be in any allowable budget category or combination of categories. When a direct cost item represents some or all of the non-Federal contribution, any associated indirect costs may not be charged to Federal funds but may be counted as part of the cost-sharing. The treatment of a contributed cost as direct or indirect must be consistent with the classification of similar items charged to DOE funds.

Valuation of in-kind contributions and documentation of cost-sharing shall be in accordance with 10 CFR 600.107.

Title to any equipment (an article of tangible personal property that has a useful life of more than 2 years and an acquisition cost of $500 or more) or supplies acquired by a nonprofit institution of higher education or a nonprofit organization whose primary purpose is the conduct of scientific research shall vest in the grantee and such equipment shall be exempt from accountability except that DOE has the right to transfer ownership of any item of equipment having a unit acquisition cost of $1,000 or more under the conditions specified in 10 CFR 600.117(d)(2). This exemption is derived from Public Law 95-224. The Federal Grant and Cooperative Agreement Act of 1977, as amended.

Title to equipment and supplies acquired by all other grantees shall vest in the grantee. However, such grantees shall be accountable for equipment with a unit acquisition cost of $1,000 or more acquired under this grant as specified in 10 CFR 600.117(d)(2), (3) and (4). For such grantees, supplies need only be accounted for at closeout and then only if they are unused and exceed $1,000 in total aggregate current fair market value. In this case accountability requires that DOE be compensated in an amount computed in accordance with Section 600.117(e) if the supplies are retained for use on non-Federal activities.

All grantees shall follow property management policies and procedures which provide for adequate control of the acquisition and use of assets acquired under the grant.

Intangible Property

Treatment, including reporting, of patent and data rights and copyrights shall be as specified in the Special Terms and Conditions of this grant.

14. Change or Absence of the Principal Investigator or Designated Key Personnel

Since the DOE decision to fund a project is based, to a significant extent, on the qualifications and level of participation of the Principal Investigator, a change of Principal Investigator or of the level of effort of the Principal Investigator is considered a change in the approved project. The approval of DOE must be obtained prior to any change of the Principal Investigator or, in certain cases, other key personnel who have been identified as key personnel in the Special Terms and Conditions of this grant. In addition, any continuous absence of the Principal Investigator in excess of three months or plans for the Principal Investigator to become substantially less involved in the project than was indicated in the approved grant application requires DOE prior approval. Grantee is encouraged to contact DOE immediately upon becoming aware that any of these changes are likely to be proposed, but in any event must do so and receive DOE prior approval before effecting any such change.

15. Changes in Objectives or Scope

Any change in the objectives or scope of a grant-supported project requires the prior approval of DOE. Such changes include changes in the phenomenon or phenomena under study and in the methodology or experiment if they are a specific objective of the research work as stated in the application approved by DOE.

16. Transfer of Substantive Programmatic Effort

None of the substantive effort of this project may be transferred by contract or subgrant to another organization or person without the prior approval of DOE. This provision does not apply to the procurement of equipment, supplies, materials, or general support services which may, however, be subject to other prior approval requirements as found, for example, in the applicable cost principles or procurement standards.

17. General Procurement Prior Approval Requirements

A grantee must receive prior approval from DOE before entering into any sole source contract or a contract where only one bid or proposal is received when the value of the contract in the aggregate is expected to exceed 1) $10,000 and the grantee is a state, local, or Indian tribal government or 2) $5,000 for all other grantees.

18. Equipment and Other Capital Expenditures

Expenditures for equipment and other capital assets having a unit acquisition cost of $500 or more require the prior approval of DOE with one exception. For special purpose equipment, prior approval is required only when the unit acquisition cost is $1,000 or more. (Special purpose equipment means equipment which is used only for research, medical, scientific, or other technical activities.)

19. Travel

Foreign Travel - DOE prior approval is required for each separate foreign trip. Foreign travel must be directly related to the project objectives. Foreign travel is any travel outside Canada and the United States and its territories and possessions or, for grantees located in another country, travel outside that country.

Domestic Travel - Such costs are allowable to the extent provided in the approved budget. In addition, grantees may exceed the approved budget amount for domestic travel by up to 25% or $500 whichever is greater, without DOE prior approval. All other expenditures for domestic travel beyond these limits require prior approval.

20. Consultant Services

Costs of consultant services are allowable subject to satisfaction of the requirements of the applicable cost principles, including the requirement that the consultant not be an employee of the grantee organization. There is one exception to the requirement that the consultant not be an employee of the grantee organization which applies to colleges and universities only. For colleges and universities, in unusual cases, and only with the prior approval of DOE, intra-organizational consultation may be permitted where consultation is across departmental lines or involves a separate or remote operation.

21. Paperwork Reduction

This award is subject to the requirements of the Paperwork Reduction Act of 1980 as implemented by the Office of Management and Budget rules, "Controlling Paperwork Burdens on the Public," published at 5 CFR 1320 (48 FR 13666, 3/31/83) if the grantee will collect information from ten or more respondents either:

A. At the specific request of DOE, or

B. If the award requires specific DOE approval of the information collection or the collection procedures.

Any proposed sponsored information collection under item 21 B. above shall be submitted by the grantee to the Contracting Officer named on the face page of this award at least 90 days prior to the intended date of information collection. DOE will seek the requisite approval from the Office of Management and Budget and will promptly notify the grantee of the disposition of the request.

22. Generally Applicable Requirements

In accordance with 10 CFR 600.12, this grant is subject to a number of statutory and other generally applicable requirements. Those requirements most pertinent to research projects are highlighted below:

Animal Welfare

Any grantee performing research on warm-blooded animals shall comply with the Laboratory Animal Welfare Act of 1966 (Public Law 89-544, as amended) and the regulations promulgated thereunder by the Secretary of Agriculture at 9 CFR Chapter 1, Subchapter A, pertaining to the care, handling, and treatment of warm-blooded animals held or used for research, teaching, or other activities supported by Federal awards. The grantee is expected to ensure that the guidelines described in Department of Health and Human Services (DHHS) Publication No. [NIH] 78-23, "Guide for the Care and Use of Laboratory Animals," are followed (Copies are available from the Superintendent of Documents, Government Printing Office, Washington, DC 20024, Stock No. 017-040-00427-3).

Research Involving Recombinant DNA Modecules

Any grantee performing research involving recombinant DNA molecules and/or organisms and viruses containing recombinant DNA molecules agrees by acceptance of this grant to comply with the National Institutes of Health "Guidelines for Research Involving Recombinant DNA Molecules," June 1983 (48 FR 24556) or such later revision of those guidelines as may be published in the Federal Register.

Use of Human Subjects in Research, Development, and Related Activities

Any DOE grantee performing research, development, or related activities involving any use of human subjects must comply with DOE regulations found at 10 CFR Part 74S "Protection of Human Subjects" and any additional Provisions which may be included in the Special Terms and Conditions of this grant. Such provisions are intended to safeguard the rights and welfare of human subjects at risk of possible physical, psychological, or social injury as a consequence of their participation.

23. Nondiscrimination

This grant is subject to the provisions of 10 CFR Part 1040 "Nondiscrimination in Federally Assisted Programs."

24. Public Access to Information

The Freedom of Information Act, as amended, and the DOE implementing regulations (10 CFR Part 1004) require the release by DOE of certain documents and records regarding grants upon written request by any member of the public. The intended use of the information will not be a criterion for release. These requirements apply to information held by DOE, and do not require grantees, their subgrantees, or their contractors to permit public access to their records.

Records maintained by DOE with respect to grants are subject to the provisions of the Privacy Act and the DOE implementing regulations (10 CFR Part 1008) if those records constitute a "system of records" as defined in the Act and the regulations. Generally, records maintained by grantees, their subgrantees, or their contractors are not subject to these requirements.

25. Acknowledgement of Support

Publication of the results of this grant, subject to any applicable restrictions in 10 CFR 600.118 ("Patents, data, and copyrights"), is encouraged. Any article which is published shall include an acknowledgement that the research was supported, in whole or in part, by a DOE grant (including the grant number), but that such support does not constitute an endorsement by DOE of the views expressed in the article.

26. National Security

It is not expected that activities under this grant will generate or otherwise involve classified information (i.e., Restricted Data, Formerly Restricted Data, National Security Information).

However, if in the opinion of the grantee or DOE such involvement becomes expected prior to the closeout of the grant, the grantee or DOE shall notify the other in writing immediately. If the grantee believes any information developed or acquired may be classifiable, the grantee shall not provide the potentially classifiable information to anyone, including the DOE officials with whom the grantee normally communicates, except the Director of Classification, and shall protect such information as if it were classified until notified by DOE that a determination has been made that it does not require such handling. Correspondence which includes the specific information in question shall be sent by registered mail to U.S. Department of Energy, Attn: Director of Classification, DP-32, Washington, DC 20545. If the information is determined to be classified the grantee may wish to discontinue the project, in which case the grantee and DOE shall terminate the grant by mutual agreement. If the grant is to be terminated, all material deemed by DOE to be classified shall be forwarded to DOE, in a manner specified by DOE, for proper disposition. If the grantee and DOE wish to continue the grant, even though classified information is involved, the grantee shall be required to obtain both personnel and facility security clearances through the Office of Safeguards and Security. Costs associated with handling and protecting any such classified information shall be negotiated at the time the determination to proceed is made.

27. Liabilities and Losses

DOE assumes no liability with respect to any damages or loss arising out of any activities undertaken with the financial support of this grant.

28. Contracting Officer's Technical Representative (COTR)

The individual identified in Block 11. of the Notice of Financial Assistance Award as the DOE Project Officer is the Contracting Officer's Technical Representative (COTR). The COTR is responsible for

1) monitoring the research efforts being conducted by the Grantee under the scope of this award; 2) advising the Contracting Officer on technical matters related to administration of the grant, including progress and status of the Grantee's research; and 3) providing technical advice and guidance to the Grantee in order to assist both the research efforts of the Grantee and the Grantee's adherence to the grant terms and conditions.

The COTR does not have the authority to:

Cause an increase or decrease in the total estimated cost of, or the time required for, the research effort being supported;

Cause any change in the express terms and conditions of the grant;

Cause any change in the objectives or scope of the effort being supported;

Act in the capacity of the Contracting Officer by issuing any approval or disapproval required by the terms and conditions of the grant;

Interfere with the Grantee's right to perform under the terms and conditions of the grant.

29. Interest

(a) Notwithstanding any other term or conditions of this grant, all amounts that become payable by the recipient to the Government under this grant shall bear simple interest from the date due until paid unless paid within 30 days of becoming due. The interest rate shall be the interest rate established by the Secretary of Treasury (Secretary) as provided in Section 11 of the Debt Collection Act of 1982 (31 U.S.C. 3717), which is applicable to the period in which the amount becomes due, as provided in paragraph (b) of this provision, and then at the rate applicable for each three-month period as fixed by the Secretary until the amount is paid.

(b) Amounts shall be due at the earliest of the following dates:

(1) The date fixed under this grant.

(2) The date of the first written demand for payment consistent with this grant, including any demand resulting from a termination.

(3) The date the Government transmits to the recipient a proposed agreement to confirm completed negotiations establishing the amount of debt.

(c) The interest charge made under this provision may be reduced in accordance with the procedures prescribed in 4 CFR 102.13 or in accordance with agency regulations in effect on the date of original award of this grant.

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STATEMENT OF WORK

1.0 INTRODUCTION

The goal of this Grant is to support cost-shared research in the form of technical assistance, on the Moana geothermal system, a moderate-temperature hydrothermal reservoir located in Reno, Nevada. The Moana resource is currently used for space heating by over 200 residences and numerous commercial establishments. Additional development is currently underway and is proceeding in an uncoordinated manner which could affect the quality and longevity of the resource. Three state agencies have regulatory responsibility over various aspects of geothermal development but a better data base and a quantitative predictive model is needed to assist these agencies and developers in sound development of the resource with minimal environmental impact. The aim of the proposed research is to obtain the necessary data and to construct, calibrate, and verify a numerical model of the Moana system. The model will be made available to developers and regulatory agencies.

2.0 SCOPE

The objectives of this grant are to construct, calibrate and verify a numerical model of the Moana geothermal reservoir. The model will be capable of simulating fluid, heat and contaminant transport under steady state or transient conditions. Initial efforts will focus on an inventory and assessment of existing data, followed by additional data collection for one full heating year (13 months). The USGS numerical model SUTRA will be used to model the Moana system and the model will be calibrated and verified with respect to the observed data. Reservoir simulation will then be completed for a number of development scenarios and the results made available to developers and regulators. All tasks will be completed in a period of 22 months.

3.0 APPLICABLE DOCUMENTS

The research described herein is abstracted from a proposal titled "Quantitative Evaluation and Numerical Simulation of the Moana Geothermal System", dated June 18, 1987, as modified on October 26, 1987. This proposal was submitted by the Desert Research Institute, University of Nevada System, in response to a DOE/ID Program Research and Development Announcement (PRDA) for State Geothermal Research and Development - PRDA No. DE-PR07-87ID12662.

4.0 TECHNICAL TASKS

The following tasks will be accomplished under this grant.

4.1 Collect and assess the quality of all relevant existing data including hydraulic data, thermal data, well data, geologic data, hydrochemical data and hydrologic data.

4.2 Collect new data on the Moana geothermal system for a period of 13 months. Perform weekly measurements of water levels and temperatures in selected wells. Design and conduct aquifer tests to characterize storage and fluid conductive properties of the reservoir and the nature of the boundaries. Determine thermal gradients in wells, and chemical analyses of well fluids.

4.3 Complete calibration and verification of a numerical model simulating the Moana geothermal reservoir using the data from Tasks 4.1 and 4.2. Verify the accuracy of the model under both steady state and transient conditions. The USGS numerical model program SUTRA will be used for the modeling and simulation of the reservoir.

4.4 Perform reservoir simulations for a variety of development scenarios using the calibrated and verified SUTRA model. The simulations will show the effects of temperature distributions due to pumping and injection; plumes of lower temperature water due to injection; solute concentrations and distributions due to pumping; high solute concentration plumes due to reinjection; and areas of decreased water levels due to groundwater withdrawal.

4.5 Complete the documentation of all new resource data, a description of the Moana reservoir model and the results and interpretation of the model simulations. Prepare a user's manual for the Moana reservoir model and deliver to the three state regulatory agencies and to interested parties.

5.0 REPORTS, DATA, AND OTHER DELIVERABLES

5.1 Reports will be due as indicated on the Federal Assistance Reporting Checklist and the Report Distribution List.

5.2 A detailed final technical report will be prepared which will document all inventoried and new resource data, and will describe the Moana reservoir model and the results and interpretation of the model simulations. A user's manual for the Moana reservoir model will be included as an appendix. Any new software developed which is necessary for the execution of the reservoir model will be described and a listing included. A draft final report will be submitted to DOE/ID for review and comment not less than 45 days prior to the scheduled delivery of the final report.

6.0 SPECIAL CONSIDERATIONS

None.

wp/Thorne/1261

REPORT DISTRIBUTION LIST

Grant No. DE-FG07-88ID12757

Report/Plan	Form No.	Frequency	No. of Copies	Address
Federal Assistance Management Summary Report	EIA-459E	Q	1,1,1,1,1	a,b,c,d,e
Notice of Energy RD&D	DOE 538	O	1,1	a,f
Technical Progress Report	N/A	Q	1,1,1,1	a,b,d,e
Topical Report	N/A	A	1,4,1,1	a,b,d,e
Final Technical Report	N/A	F	1,4,1,1	a,b,d,e
Financial Status Report	SF 269	F	1,1,1	a,b,c

LIST OF ADDRESSEES

a. U.S. Department of Energy
785 DOE Place
Idaho Falls, ID 83402
Attn: Trudy A. Thorne

b. Same as above
Attn: Kenneth J. Taylor

c. Same as above
Attn: Earl Jones

d. U.S. Department of Energy
Forrestal Bldg., CE-342
1000 Independence Ave, SW
Washington, DC 20585
Attn: Marshall Reed

e. University of Utah Research Institute
Earth Science Laboratory
391 Chipeta Way, Suite C
Salt Lake City, UT 84108-1295
Attn: Howard Ross

f. U.S. Department of Energy
Technical Information Center
P.O. Box 62
Oak Ridge, TN 37830

Grant No. DE-FG07-88ID12757
Part V - Reporting Requirements

U.S. DEPARTMENT OF ENERGY

FEDERAL ASSISTANCE REPORTING CHECKLIST

FORM EIA-459A (10-80)

FORM APPROVED OMB NO 1900-0127

1. Identification Number: DE-FG07-88ID12757

2. Program/Project Title: Evaluation and Simulation of Moana Geothermal System

3. Recipient: Univ. of Nevada System, Desert Research Institution

4. Reporting Requirements:

	Frequency	No. of Copies	Addressees
PROGRAM/PROJECT MANAGEMENT REPORTING			
[ ] Federal Assistance Milestone Plan			
[ ] Federal Assistance Budget Information Form			
[X] Federal Assistance Management Summary Report	Q	1,1,1,1,1	a,b,c,d,e
[ ] Federal Assistance Program/Project Status Report			
[X] Financial Status Report, OMB Form 269	F	1,1,1	a,b,c
TECHNICAL INFORMATION REPORTING			
[X] Notice of Energy RD&D	O	1,1	a,f
[X] Technical Progress Report	Q	1,1,1,1	a,b,d,e
[X] Topical Report	A	1,4*,1,1	a,b*,d,e
[X] Final Technical Report	F	1,4*,1,1	a,b*,d,e

FREQUENCY CODES AND DUE DATES:

- A - As Necessary; within 5 calendar days after events
- F - Final; 90 calendar days after the performance of the effort ends.
- Q - Quarterly; within 30 days after end of calendar quarter or portion thereof.
- O - One time after project starts; within 30 days after award.
- X - Required with proposals or with the application or with significant planning changes.
- Y - Yearly; 30 days after the end of program year. (Financial Status Reports 90 days).
- S - Semiannually; within 30 days after end of program fiscal half year.

5. Special Instructions:

*3 copies plus a camera-ready copy

6. Prepared by: (Signature and Date) [signature] 1-4-88

7. Reviewed by: (Signature and Date) Sandy Thorne 2/10/88

To: Dr. Elizabeth Jacobson

From: Howard Ross, UURI

Subject: NCTE notification letter for Univ. Nevada, Desert Research Institute

Date: March 29, 1990

Letter to: Mr. Kenneth K. Osborne
Contracts Specialist, DOE/ID

Re: DOE Research Grant, DE-FG07-88ID12757; Notification of No-cost Time Extension

Dear Mr. Osborne:

Several situations have occurred during our work on the research project "Evaluation and Simulation of the Moana Geothermal System", Grant DE-FG07-88ID12757, which resulted in project delays and make it impossible to complete this project as scheduled. The initial Principal Investigator, Dr. Michael Campana, left DRI only six weeks after the start of the project requiring the naming of a new Principal Investigator. The logistics required to begin the monitoring program (in all private wells) delayed data collection by approximately two months. Other problems were related to accessing the monitoring wells, training graduate students, and compiling input data for the numerical model. Because of these and other delays we have granted ourselves, UNLV-Desert Research Institute, a five month no-cost time extension, changing the Budget Period and Project Period termination date from April 30, 1990 to September 30, 1990. This change in the final budget period of the project is provided for by 10 CFR Part 600, Section 600.31 (d) as amended by FR Doc. 89-24243, Filed 10-12-89. No additional Federal funds are requested.

In addition I request DOE approval for a reallocation of project funding categories. Due largely to problems described above, it is necessary to transfer $________ previously budgeted for operations to salaries, increasing the project budget for salaries to $________. This transfer involves less than five percent of the total project budget and appears to be provided for in Special Terms and Conditions for Research Grants, items 2 and 7. No additional Federal funds are requested.

>10%?

Please call me if you require additional information on these matters.

Sincerely,

DESERT RESEARCH INSTITUTE
University of Nevada System

Water Resources Center—Reno/Las Vegas

7010 Dandini Blvd.
Reno, NV 89512
(702) 673-7361
Fax: (702) 673-7397

Mailing Address: P.O. Box 60220
Reno, Nevada 89506-0220

Rec April 15, 1991 HPR

April 12, 1991

Kenneth Taylor
U.S. Department of Energy
Idaho Operations Office, 785 DOE Place
Idaho Falls, ID 83402

Dear Mr. Taylor:

Enclosed is three (3) copies and one (1) original of the final report entitled "The Moana Geothermal System in Reno, Nevada: A Hydrologic, Geochemical, and Thermal Analysis," which completes this grant under the State Cooperative Geothermal Research program (grant number DE-FG07-88ID12757). This report fulfills the requirements of the contract.

Your help with this project has been appreciated. If additional information is needed, please let me know.

Sincerely,

Elizabeth Jacobson

Elizabeth A. Jacobson
Assistant Research Professor

EAJ:dlw
w/Encl.
cc: Scott D. Applonie, DOE Idaho (1)
Howard Ross, UURI (1)
Marshall Reed, DOE DC (1)
Jack Hess, DRI (1)
Karla Cosens, DRI (1)
Marjory Jones, DRI (1)

DESERT RESEARCH INSTITUTE
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Fax: (702) 673-7397

Mailing Address: P.O. Box 60220
Reno, Nevada 89506-0220

February 20, 1991

Ms. Elizabeth Bowhan
U.S. Department of Energy
785 DOE Place
Idaho Falls, Idaho 83402

Dear Ms. Bowhan:

I am writing to you concerning my DOE project, grant number DE-FG07-88ID12757, which is scheduled for completion on February 28, 1991. The final report has just been completed and sent on February 16, 1991 by Federal Express to Howard Ross at UURI and Marshall Reed at DOE in Washington, D.C. for their review.

If they are able to expedite their reviews, I plan on making every attempt to meet the February 28, 1991 deadline for submission of the final report. Because of the short time until the deadline, it has been suggested that I formally request an additional no-cost time extension and allow you to make the decision if it is necessary or not.

As you know, I have already granted myself a no-cost time extension and requested an additional one from you in my letter dated August 23, 1990. I appreciate the additional time and as I have stated, will make every attempt to meet the February 28, 1991 deadline. However, in case I don't meet the deadline, I am formally requesting an additional no-cost time extension with project termination on April 30, 1991.

I thank you for considering this request. Please call me at (702) 673-7373 if you require additional information on these matters.

Sincerely yours,

Elizabeth Jacobson

Elizabeth Jacobson
Assistant Research Professor

EJ:bjn

cc: Howard Ross
Kenneth Taylor

DESERT RESEARCH INSTITUTE
University of Nevada System
Water Resources Center

7010 Dandini Blvd.
Reno, NV 89512
(702) 673-7361
Mailing Address: P.O. Box 60220
Reno, Nevada 89506-0220

June 30, 1988

Mr. Kenneth J. Taylor
U.S. DOE, Idaho Operations Office
785 DOE Place
Idaho Falls, Idaho 83402

Subj: Grant No. DE-FG07-88ID12757, Water Resources Center, Desert Research Institute

Dear Mr. Taylor:

The purpose of this letter is to request approval for a change in Project Management on the subject grant from Dr. Michael Campana to Dr. Elizabeth Jacobson for the time period of August 1, 1988 to June 30, 1989 at which time Dr. Campana will be on sabbatical leave. Several points to consider while evaluating this request follow.

- During the time Dr. Campana will be on sabbatical, much of the work will involve the assessment of existing data and data collection (Tasks I & II). These two tasks are still to be supervised by Mr. W.A. McKay as indicated in the original proposal.
- The model calibration/verification work (Task III), which extends from 10/15/88 through 10/15/89 will be in excellent hands with Dr. Jacobson as Project Manager, since her modeling skills are greater than Dr. Campana's. When her talents are combined with Dr. Wheatcraft's and those of Dr. Tom Brikowski's, a new faculty member with substantial experience in the simulation of fluid and thermal flow systems, it is apparent that the modeling talent available will be greater than that originally proposed.
- Dr. Campana will be back for the final 10 months and the entirety of the final two tasks, Tasks IV and V, and will be around at the beginning to ensure that the project gets off on the right track.
- Dr. Campana will be returning to Reno several times during the course of his sabbatical and intends to stay involved in the project to the extent that this is possible.

I am confident that Dr. Jacobson's modeling expertise combined with her management skills make her an excellent choice as Project Manager during Dr. Campana's absence. I have enclosed a copy of Dr. Jacobson's vita for your review. Thank you for your consideration of this request. If you have questions please call me at (702) 673-7365.

Sincerely yours,

Paul R. Fenske
Executive Director

PRF:kkc

Enclosure as indicated

ELIZABETH A. JACOBSON

EDUCATION

1971 B.A., Mathematics and Physics, California State College, San Bernardino, California

1975 M.S., Atmospheric Physics, University of Arizona, Tucson, Arizona

1985 Ph.D., Hydrology, University of Arizona, Tucson, Arizona

HONORS AND AWARDS

Graduated from California State College, San Bernardino, with honor and with department honor in Math.

PROFESSIONAL AFFILIATIONS

American Geophysical Union
Society of Petroleum Engineers of AIME
National Water Well Association

EXPERIENCE

Dr. Jacobson has specialized in the development and improvement of parameter estimation (inverse) methodology as it applies to determining spatial variability of hydraulic properties of groundwater flow systems. She maintains an active research interest in the subjects of geostatistics and kriging (used to characterize spatial variability in hydraulic properties from measured data), conditional simulation, sensitivity and uncertainty techniques as they apply to groundwater flow systems. Her applied research efforts have involved code development for estimating hydraulic parameters of groundwater flow models, application of kriging and statistical inverse techniques to field data from an unconfined aquifer, and an investigation of uncertainty in groundwater travel time caused by uncertainty in hydraulic conductivity and porosity. Projects to which she has been a major contributor include:

- <u>DOE/Exploratory Research</u>. The exploratory research involved development and application of a technique for determining the optimum number of parameters that can be successfully identified with a parameter estimation (inverse) method. The technique was applied to data from an unconfined aquifer in Southern Arizona.

- <u>NRC/Stochastic Flow Modeling</u>. The work for NRC involved application of geostatistical techniques to a two-dimensional saturated hydraulic conductivity data set to estimate the mean, variance, and correlation lengths (i.e., two-dimensional covariance).

- <u>DOE/PNL Hazardous Materials Monitoring Program</u>. The work for this project involved application of a parameter estimation (inverse) method to the unconfined aquifer at the Hanford Site. The spatial distribution of transmissivities was estimated with the inverse method to produce a calibrated groundwater flow model of the unconfined aquifer. Both estimates of transmissivity and their associated estimation errors were obtained from the application of the inverse method.

- EPRI/Geohydrochemical Models–Interim Improvements. The work for EPRI involved kriging hydraulic head and aquifer thickness data to obtain estimates at points where no data exist. Kriging is an interpolation technique that yields estimates of data and the associated estimation errors.

- DOE/HO Performance Assessment Scientific Support (PASS) Program. The work for PASS involved a review and evaluation of the NRC and DOE approaches to sensitivity and uncertainty analysis for performance assessment. A comparison of three uncertainty methods (Monte Carlo with random sampling, Monte Carlo with Latin Hypercube sampling and first-order method) was conducted using groundwater flow data. The uncertainty methods were applied to a groundwater flow model to calculate the uncertainty in groundwater travel time caused by the uncertain hydrologic variables.

- Basalt Waste Isolation Project (BWIP) Interagency Hydrologic Working Group. The work for BWIP involved a preliminary review of the feasibility of applying parameter estimation (inverse) methods to large-scale aquifer tests in a confined aquifer composed of rocks with low hydraulic conductivity. Questions raised concerned the effect of uncertain boundary conditions on the inverse solution, the quality and quantity of data necessary for a meaningful inverse solution, and the effect on the estimates of the parameters produced by including vertical leakage.

- Hanford Site Performance Assessment Program. The work for this project involved delineating the methods of uncertainty analysis that can be applied to the performance assessments for waste disposal at the Hanford site.

- Nevada Nuclear Waste Storage Investigation (NNWSI) Performance Assessment. Work performed for this project involved a sensitivity and uncertainty analysis of groundwater travel time for the flow system near the nuclear waste repository site in Nevada. The affect of both spatial variability and uncertainty of aquifer parameters (i.e., hydraulic conductivity and porosity) on the uncertainty in travel time was investigated. Technology applications included a perturbation method for the sensitivity analysis, and Monte Carlo and first-order approaches for the uncertainty analysis.

Private consulting work involved using a numerical model to fit data from a two-well tracer test to estimate porosity and dispersion coefficient (for Hydro Geo Chem in Tucson, Arizona) and numerical modeling of a groundwater flow system in New Mexico to investigate the impact on the flow system due to dewatering at a mine site (for W.K. Summers and Associates, Socorro, New Mexico). Dr. Jacobson is a reviewer for the Water Resources Research Journal.

SCIENTIFIC ARTICLES

Nelson, R.W., E.A. Jacobson, and W. Conbere, 1987. "An Approach to Uncertainty Assessment for Fluid Flow and Contaminant Transport Modeling in Heterogeneous Groundwater Systems." Advances in Transport Phenomena in Porous Media, edited by Jacob Bear and M. Yavuz Corapcioglu, pp. 703–726. Martinus Nijhoff Publishers, Dordrecht, The Netherlands.

Jacobson, E.A., 1987. "Comparison of Inverse Modeling Results with Measured and Interpolated Hydraulic Head Data." In Proceedings of Solving Ground Water Problems with Models, pp. 675–700. National Water Well Association, Dublin, Ohio.

Nicholson, T.J., P.J. Wierenga, G.W. Gee, E.A. Jacobson, D.D. McLaughlin, and L.W. Gelhar, 1987. "Validation of Stochastic Flow and Transport Models for Unsaturated Soils: A Comprehensive Field Study." To be published in Proceedings of DOE/AECL '87 Conference on Geostatistical, Sensitivity, and Uncertainty Methods for Ground-Water Flow and Radionuclide Transport Modeling. San Francisco, California.

Neuman, S.P. and E.A. Jacobson, 1984. "Analysis of Nonintrinsic Spatial Variability by Residual Kriging with Application to Regional Ground-Water Levels." Mathematical Geology, 16(5):499-521.

Neuman, S.P., G.E. Fogg, and E.A. Jacobson, 1980. "A Statistical Approach to the Inverse Problem of Aquifer Hydrology. 2. Case Study." Water Resources Research, 16(1):33-58.

Jacobson, E.A. and E.P. Krider, 1976. "Electrostatic Field Changes Produced by Florida Lightning." Journal of Atmospheric Sciences, 33:103-117.

REPORTS

Jacobson, E.A., M.D. Freshley, and F.H. Dove, 1985. Investigations of Sensitivity and Uncertainty in Some Hydrologic Models of Yucca Mountain and Vicinity. PNL-5306 (SAND84-7212), Pacific Northwest Laboratory, Richland, Washington.

Doctor, P.G., E.A. Jacobson, and J.A. Buchanan, 1985. A Comparison of Uncertainty Analysis Methods Using a Groundwater Flow Model. A letter report to DOE Headquarters, Office of Geologic Repository Deployment, by Pacific Northwest Laboratory, Richland, Washington.

Jacobson, E.A., 1984. Identification of NRC and DOE Projects' Approaches to Sensitivity and Uncertainty Analysis As Applied to Hydrologic and Transport Models. A letter report to DOE Headquarters, Office of Geologic Repository Deployment, by Pacific Northwest Laboratory, Richland, Washington.

PRESENTATIONS

Jacobson, E.A., 1987. "Geostatistical Analysis of Two-Dimensional Saturated Hydraulic Conductivity Data." Poster paper presented at 1987 Fall Meetings of American Geophysical Union, San Francisco, California.

Nelson, R.W., E.A. Jacobson, and W. Conbere, 1985. "Uncertainty Assessment for Fluid Flow and Contaminant Transport Modeling in Heterogeneous Groundwater Systems." Presented at the Symposium on Groundwater Flow and Transport Modeling for Performance Assessment of Deep Geologic Disposal, May 20-21, 1985, Albuquerque, New Mexico.

Jacobson, E.A. and S.P. Neuman, 1982. "Statistical Inverse Modeling of Aquifers Using Surrogate Parameters." Invited paper presented at the Annual Fall Meeting of the American Geophysical Union, December 7-15, 1982.

Neuman, S.P., A. Binsariti, and E.A. Jacobson, 1980. "Statistical Analysis and Stochastic Modeling of the Cortaro Aquifer in Southern Arizona." Presented at the American Geophysical Union Fall Meeting, December 1980.

Krider, E.P., E.A. Jacobson, and J.M. Livingston, 1975. "Electrostatic Field Changes Produced by Lightning at the NASA Kennedy Space Center." Presented at the Annual Fall Meeting of the American Geophysical Union, December 1975.

Jacobson, E.A., E.P. Krider, and J.M. Livingston, 1975. "The Electrical Evolution of Summer Thunderstorms at the NASA Kennedy Space Center." Presented at the Annual Fall Meeting of the American Geophysical Union, December 1975.

Jacobson, E.A. and E.P. Krider, 1974. "Electrostatic Field Changes and Recovery Curves Produced by Florida Lightning." Presented at Cloud Physics Conference in Tucson, Arizona, October 1974.

Department of Energy

Idaho Operations Office
785 DOE Place
Idaho Falls, Idaho 83402

July 13, 1988

Mr. Paul R. Fenske, Executive Director
Desert Research Institute
7010 Dandini Blvd.
Reno, NV 89512

SUBJECT: Change of Project Management For Grant No. DE-FG07-88ID12757

Dear Mr. Fenske:

In response to your June 30, 1988, letter, I approve of your proposed change of project management from Dr. Michael Campana to Dr. Elizabeth Jacobson for the time period of August 1, 1988, to June 30, 1989. It does not appear that a grant modification will be needed for this temporary change.

Dr. Jacobson's qualifications are quite impressive which indicates that you have made a very good decision on a temporary replacement for Dr. Campana. I am happy to see that Dr. Campana plans to stay involved with the project during his sabbatical. It would be nice if Dr. Jacobson would contact Howard Ross at UURI and introduce herself. Howard will be her primary technical contact for the subject grant. If I can be of any further assistance, do not hesitate to contact me.

Very truly yours,

Ken Taylor

Kenneth J. Taylor
Project Manager
Advanced Technology Division

cc: Trudy Thorne, DOE-ID
Howard Ross, UURI

WASHINGTON STATE DEPARTMENT OF
Natural Resources

BRIAN BOYLE
Commissioner of Public Lands

Division of Geology & Earth Resources
Rowesix Bldg. 1, MS:PY-12
4224 6th Ave. SE
Lacey, WA 98503
(206) 459-6372

October 16, 1989

Rec 10/19/89

Howard Ross
University of Utah Research Inst.
Earth Science Lab
391 Chipeta Way, Suite C
Salt Lake City UT 84108-1295

Dear Howard:

I have enclosed 4 copies of the final report on age dates and Quaternary Volcanic rocks. I hope the changes and expansion take care of the requested corrections from the earlier draft. Let me know.

Sincerely,

Michael A. Korosec

Michael Korosec
Geologist

MK:jl

Copies to:
Marshall Reed
Ken Taylor

WASHINGTON STATE DEPARTMENT OF
Natural Resources

BRIAN BOYLE
Commissioner of Public Lands

Division of Geology & Earth Resources
Rowesix Bldg. 1, MS:PY-12
4224 6th Ave. SE
Lacey, WA 98503
(206) 459-6372

Ken Taylor, Contract Officer
Trudy Thorne, Contract Officer
U.S. Department of Energy
782 DOE Place
Idaho Falls, ID 83402

November 28, 1989

RE: Grant No DE-FG07-88ID 12740

Dear Sir and Madame:

Letter Report: Contract Problems

During work on this project, we encountered numerous problems with the contractor and subcontractor, involving the number of samples to be dated and the quality of the age date determinations. The following is a summary of those problems.

Early in the program to obtain new age dates for the Indian Heaven volcanic field, the Division was informed that the originally planned 12 samples to be dated (through a contract between the U. S. Department of Energy and the University of Arizona) would be limited to 10. But the good news was that 10 to 12 additional age date determinations would be possible through a new contract with a different lab. As it was described to us, this was to come about as soon as the Department of Energy located an Ar-Ar dating lab it felt confident about. We did not know at the time that funds had never been identified or appropriated for this work.

In an effort to close out an old contract, the Department of Energy encouraged us to send 10 samples to the University of Arizona age dating laboratory as soon as we could. The University of Arizona lab uses a K-Ar age dating technique which, while having been adequate in the past for dating Quaternary rocks, has been improved upon by newer state-of-the-art techniques employing Ar-Ar dating. The Division sent materials collected from Indian Heaven, mostly older volcanic flows, to the University of Arizona lab, with the expectation of being able to receive 10 to 12 additional dates. Younger and key flows were saved for the Ar-Ar dating. This was an approach encouraged by the Department of Energy.

After many months it was eventually determined that a lab had not been found and funds were not going to be appropriated for the additional age dating. During that time, problems developed with the University of Arizona laboratory. Preliminary results from the first 5 samples were phoned in to us in December, 1988, and 4 of these were documented on data sheets sent through the mail. We were assured that the results had been checked by lab director Paul Damon before release. In April, we were informed by phone that a research assistant "who was accident prone" modified both tracer concentrations and compositions without their knowledge, requiring recalculation of analyses. While they had known about this for some time, they failed to inform of us this development until the phone call. The data was mailed to us 7 weeks after that call, arriving June 8.

The results were significantly different from the original reported data. One thing which seemed quite odd was that two samples which had given very similar results the first time, Basalt of Thomas Lake and Basalt of Burnt Peak, with originally determined dates of 1.74 $\pm$ 0.09 and 1.74 $\pm$ 0.13 m.y. b.p. and very similar potassium concentrations (0.195 and 0.198 percent), were reanalyzed to have quite different ages, 217,000 and 309,000 yr b.p. respectively. Apparently, the potassium was reanalyzed for the Thomas Lake sample (with a result of 0.104 percent, a 47 percent change), but not for the Burnt Peak sample. Since Burnt Peak sits unconformably atop Thomas Lake, this is doubly troubling. It was also noted that the andesite of Forlorn Lake and Basalt of Trout Lake Creek were not reanalyzed for potassium concentrations.

The net result of this is that in spite of the reassurances from M. Shafiqullah, Research Scientist at University of Arizona age dating lab, we have serious doubts about the accuracy and validity of the dates, and we use them in this report with severe apprehension.

In addition, the overall low yield of K from the ground mass plagioclase for many of the samples, and low Ar for a few, would bring the age values into question even without the other problems described above.

I hope this letter provides an understanding as to why there may be discrepancies between the original contract proposals and the final results described in the two project reports.

Sincerely,

Michael A. Korosec

Michael A. Korosec
Geologist
Department of Natural Resources
Division of Geology and Earth Resources
Olympia, WA 98503

MAK:jl

cc: Howard Ross, UCRI

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STATE OF WASHINGTON

DEPARTMENT OF NATURAL RESOURCES

NEW K-AR AGE DATES GEOCHEMISTRY, AND STRATIGRAPHIC DATA FOR THE INDIAN HEAVEN QUATERNARY VOLCANIC FIELD, SOUTH CASCADE RANGE, WASHINGTON

by

Michael A. Korosec

WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES

OPEN FILE REPORT 89-

DISCLAIMER

CONTENTS

New K-Ar Age Dates, Geochemistry, and Stratigraphic Data for the Indian Heaven Quaternary Volcanic Field, Southern Cascade Range, Washington

by

Michael A. Korosec

INTRODUCTION

As part of the Washington geothermal exploration program, the Division of Geology and Earth Resources has been involved with studies of the state's major volcanoes and volcanic fields. The first major geothermal project by the Division involved geologic mapping and the drilling of 5 temperature gradient/heat flow holes in the Indian Heaven area in 1975 (Schuster and others, 1978). Funding was provided by the National Science Foundation. From 1980 to 1983, U.S. Department of Energy contracts funded the geochemical analysis of over 100 samples from Indian Heaven and surrounding volcanic fields, and lead to the dating of several of the flows. The data was summarized in Hammond and Korosec, (1983). Table 1 of this report lists the age dating results from these previous studies. Uncertainties about the existing age date determinations discouraged attempts to formulate a meaningful time-space-composition-volume model for the southern Cascade Range volcanic fields.

With the promise of better age dating techniques and laboratories, the Division set out to improve the understanding of these rocks, with the hope of developing a new, more detailed and accurate model. This project was part of a larger program of temperature gradient and heat flow drilling in the southern Cascades Range. Funding for the age dates was provided through an existing U. S. Department of Energy grant to the University of Arizona.

DATA COLLECTION AND PRESENTATION

During the summer field seasons in 1987 and 1988, 45 samples of basalt, basaltic andesite, and andesite were collected from flows of the Indian Heaven volcanic field. Ten samples were K-Ar dated using groundmass plagioclase, and the results are presented in Table 2. Twenty eight samples were analyzed for whole rock major and trace element geochemistry by XRF at the Washington State University

Table 1. Previously determined age dates for the Indian Heaven volcanic field.

No.	Original Sample No.	Unit	Map Symbol*	Latitude N. o, ', "	Longitude W. o, ', "	Twn	Rng	1/4 1/4 Section	Material Dated	Percent K_2O	^{40}Ar M/gm x 10 E12	Per Cent ^{40}Ar/Total Ar	Age (k.y.)	Lab	Ref
01	128	Basaltic andesite of Juice Creek	Qvjc	45 56 46	121 53 17	5 N	7 E	SE, SE, 28	Whole rock	0.609	3.421	25.9	1,400 +/- 60	3	a
02	017	Andesite of Black Creek	Qvbc	45 53 37	121 50 02	5 N	8 E	NE, SE, 30	Whole rock	0.761	3.562	3.3	3,300 +/- 250	3	a
03	16	Basalt of Tillicum Creek	Qvtc	46 08 37	121 46 21	8 N	8 E	NE, NW, 35	Whole rock	0.284	0.19	17.25	470 +/- 40	4	a
04	14	Basalt of Sawtooth Mountain	Qvst	46 06 08	121 47 50	7 N	8 E	SE, SE, 09	Whole rock	1.219	1.448	12.9	850 +/- 50	3	a
05	30	Basalt of Trout Lake Creek	Qvtl	46 05 27	121 41 48	7 N	9 E	NE, NE, 20	Whole rock	0.031	0.438	10.43	980 +/- 120	4	a
06	28a	Basalt west of Skull Creek	Qvsk	46 04 05	121 38 59	7 N	9 E	SE, NW, 25	Whole rock	0.65	0.87	-----	930 +/- 820	2	a
07	28b	Basalt west of Skull Creek	Qvsk	46 04 05	121 38 59	7 N	9 E	SE, NW, 25	Whole rock	0.638	1.23	52.2	1,340 +/- 20	4	a
08	12	Basalt of Thomas Lake	Qvth	46 05 07	121 54 46	7 N	7 E	SE, SE, 15	Whole rock	0.27	52.4	2.7	3,700 +/- 500	1	a

Table 1 (cont.). Previously determined age dates for the Indian Heaven volcanic field.

No.	Original Sample No.	Unit	Map Symbol*	Latitude N. o, ', "	Longitude W. o, ', "	Twn	Rng	1/4 1/4 Section	Material Dated	Percent K_2O	^{40}Ar M/gm x 10 E12	Per Cent ^{40}/Ar Total Ar	Age (k.y.)	Lab	Ref
09	-	Basaltic andesite of Meadow Creek	Qvme	46 05 40	121 43 30	7 N	9 E	SW, NW, 18	Whole rock	0.823	1.429	36.7	1,210 +/- 50	2	b
10	-	Basalt of Little Goose Creek	Qvlg	46 02 55	121 42 35	5 N	8 E	NE, SE, 30	Whole rock	0.738	0.02987	0.02	28 +/- 400	3	b
11	-	Basalt of Lone Butte (dike)	Qvlb	46 03 08	121 50 34	7 N	7 E	SW, NW, 32	Whole rock				252 +/- 7	6	c
12	-	Basalt of Lone Butte (pillow)	Qvlb	46 03 08	121 50 41	7 N	7 E	SE, NW, 31	Whole rock				91 +/- 10	6	c
13	-	Basalt of Burnt Peak	Qvbp	46 03 25	121 54 09	7 N	7 E	SE, SE, 26	Whole rock				160 +/- 38	6	c
14	-	Basalt of Goose Lake	Qvgl	45 57 00	121 45 55	7 N	7 E	NW, SE, 32	Whole rock	0.537	54.80	1.1	795 +/- 28	3	b
15	-	Basalt of Big Lava Bed	Qvbl	45 56 06	121 41 00	5 N	9 E	NW, SE, 8	^{14}C (Twigs)				8.1 +/- .11	5	a
16	-	Basalt of Big Lava Bed	Qvbl	45 54 42	121 41 55	5 N	9 E	NE, NE, 20	^{14}C (Twigs)				8.2 +/- .10	5	a
17	-	Basalt of Lake Comcomly	Qvlc	45 58 00	121 44 45	6 N	8 E	SW, NE, 21	^{14}C (Twigs)				29 +/- .1	5	b
18	-	Basalt of Lake Comcomly	Qvlc	45 58 00	121 44 45	6 N	8 E	SW, NE, 21	^{14}C (Branch)				30.3 +/- 1.0	5	b

Laboratories

1. H. W. Fairhall, University of Washington, 1981
2. S. H. Evans, University of Utah Research Institute, 1981-1982
3. E. H. McKee, U. S. Geological Survey, Menlo Park, CA 1982
4. R. A. Duncan, Oregon State University, 1982
5. Meyer Rubin, U.S. Geological Survey, Reston, VA, 1981
6. R. A. Duncan, Oregon State University, 1988

References

a. Hammond and Korosec, 1983
b. Paul Hammond, personal communication, 1983
c. Paul Hammond, personal communication, 1988

* Map symbols are from the Hood River and Mount Adams 1:100,000 scale geologic maps (Korosec, 1987a, 1987b)

Table 2. New K-Ar age dates Indian Heaven Volcanic Field from the University of Arizona

No.	Sample Number	Unit Name	Map Symbol*	Latitude	Longitude	Twn	Rng	1/4	1/4	Sec.	% K_2O	^{40}Ar	% ^{40}Ar/ Total Ar	Age (Thousand Years)
1	MK87-9-70	Andesite of Forlorn Lake	Qvfl	45 56 55	121 45 32	5N	8E	NE	SE	2	.798	.173	3.5	125 $\pm$ 14
2	MK88-8-8	Basalt of Thomas Lake	Qvth	46 05 02	121 54 51	7N	7E	SW	SW	14	.104	.039	2.0	217 $\pm$ 122
3	MK88-8-9	Basalt of Burnt Peak	Qvbp	46 03 25	121 54 09	7N	7E	SE	SE	26	.198	.106	4.0	309 $\pm$ 75
4	MK88-8-10	Basalt of Trout Lake Creek	Qvtl	46 05 06	121 60 36	7N	9E	NW	NW	29	.241	.206	5.2	492 $\pm$ 84
5	MK88-9-75	Basaltic andesite of Lone Butte	Qvlb	46 03 08	121 50 41	7N	7E	SE	NW	31	.971	.529	3.0	314 $\pm$ 54
6	MK88-8-14	Basalt of Tillicum Creek	Qvtc	46 08 13	121 46 48	8N	8E	NW	NW	35	.086	.249	1.5	1,670 $\pm$ 230
7	MK88-8-11	Andesite of Meadow Creek	Qvme	46 05 39	121 43 33	7N	9E	SE	NW	18	.800	.288	12.5	277 $\pm$ 20
8	MK88-8-18	Andesite of Black Creek	Qvbc	45 53 36	121 50 38	5N	8E	NE	SE	30	.750	.264	10.0	203 $\pm$ 36
9	MK88-8-20	Andesite of Juice Creek	Qvje	46 56 23	121 54 13	5N	7E	NW	NW	11	1.142	.578	13.8	292 $\pm$ 33
10	MK88-8-24	Basalt of Sawtooth Mountain	Qvst	46 05 59	121 47 45	7N	8E	NW	NW	15	1.089	.744	21.7	394 $\pm$ 39

*Map symbols are from the Hood River and Mount Adams 1:100,000 Geologic Maps (Korosec 1987a, 1987b)
Dated Material = Groundmass Plagioclase

Table 3. Major elements geochemical data for Quaternary volcanic rocks of the Mount Adams and Hood River 1:100,000 quadrangle. All analyses by XRF, Washington State University. All analyses normalized to 100 wt. %.

Sample	Unit	Subsection	Section	Twp	Rge	SiO2	Al2O3	TiO2	FeO*	MnO	CaO	MgO	K2O	Na2O	P2O5
MK8887	BASALT OF BURNT PEAK	SW/4 SW/4	14	07	7E	49.08	17.56	1.27	9.85	0.17	10.33	8.19	0.38	3.02	0.17
MK8888	BASALT OF THOMAS LAKE	SW/4 SW/4	14	07	07E	49.11	17.59	1.24	9.87	0.17	10.38	8.19	0.27	3.05	0.13
MK8889	BASALT OF BURNT PEAK	SE/4 SE/4	26	07	07E	49.58	18.01	1.13	10.01	0.17	10.04	7.63	0.28	3.02	0.13
MK88810	BASALT OF TROUT LAKE CREEK	NW/4 NW/4	29	07	09E	49.52	18.19	1.13	9.47	0.16	10.44	7.46	0.34	3.14	0.14
MK88811	ANDESITE OF MEADOW CREEK	SE/4 NW/4	18	07	09E	52.28	17.60	1.46	8.16	0.14	8.20	7.12	0.87	3.86	0.31
MK88813	BASALT OF TILLICUM CREEK	NW/4 NW/4	35	08	08E	47.93	17.50	1.33	10.05	0.17	10.59	9.17	0.27	2.83	0.15
MK88814	BASALT OF TILLICUM CREEK	NW/4 NW/4	35	08	08E	47.76	17.49	1.45	10.45	0.18	10.69	8.68	0.22	2.91	0.17
MK88815	BASALT OF TWIN BUTTE (WEST)	SW/4 SW/4	2	07	08E	50.14	17.29	1.35	9.62	0.17	9.88	7.36	0.82	3.15	0.22
MK88816	ANDESITE OF BLACK CREEK	SW/4 NE/4	5	04	08E	54.45	17.24	1.12	7.09	0.12	7.86	6.67	1.27	3.85	0.34
MK88818	ANDESITE OF BLACK CREEK	NE/4 SE/4	30	05	08E	56.37	17.96	1.07	6.78	0.11	6.93	5.34	0.90	4.27	0.27
MK88820	ANDESITE OF JUICE CREEK	NW/4 NW/4	11	05	07E	54.31	16.94	1.07	7.15	0.12	8.05	7.11	1.24	3.72	0.29
MK88822	ANDESITE OF JUICE CREEK	NW/4 SE/4	12	05	07E	55.87	17.22	1.11	6.44	0.11	7.36	6.20	1.38	4.00	0.31
MK88823	BASALT OF MOSQUITO CREEK	NW/4 NW/4	36	08	08E	48.17	16.55	1.88	10.17	0.17	9.53	9.64	0.77	2.77	0.35
MK88824	BASALT OF SAWTOOTH MOUNTAIN	NW/4 NW/4	15	07	05E	50.86	16.57	1.26	9.65	0.15	8.89	7.91	1.12	3.31	0.28
MK88826	BASALT OF RED LAKE	NE/4 NE/4	22	07	08E	50.76	16.18	1.39	8.94	0.14	9.19	7.97	1.54	3.47	0.42
MK8891	BASALT OF INDIAN HEAVEN	SW/4 SW/4	1	06	07E	50.61	17.72	1.22	9.32	0.16	10.06	7.06	0.51	3.15	0.19
MK8893	BASALT OF SHEEP LAKES	NE/4 SE/4	8	05	08E	52.32	17.21	1.52	9.00	0.14	8.06	6.51	0.96	3.88	0.39
MK8894	BASALT OF ICE CAVES	SW/4 NE/4	35	06	09E	49.86	17.22	1.31	10.80	0.17	9.93	7.19	0.27	3.09	0.16
MK8895	BASASLT OF LITTLE GOOSE CREEK	NE/4 NE/4	32	07	09E	50.18	16.47	1.79	9.20	0.15	8.93	8.20	1.10	3.62	0.37
MK870968	BASALT OF THE WART	NE/4 NW/4	20	05	08E	54.02	18.03	1.21	7.56	0.12	7.70	6.65	0.74	3.70	0.28
MK870969	BASALT SOUTH OF THE WART	SW/4 NE/4	20	05	08E	52.52	17.41	1.50	8.99	0.14	7.95	6.65	0.91	3.56	0.37
MK870970	ANDESITE OF FORLORN LAKE	NE/4 SE/4	2	05	08E	58.64	18.09	0.93	6.30	0.10	6.63	3.92	0.91	4.20	0.27
MK870971	BASALT OF LAKE COMCOMLY	SW/4 NE/4	36	06	08E	50.50	17.45	1.26	9.46	0.17	9.89	7.15	0.59	3.32	0.21
MK870972	BASALT OF DRY CREEK	SW/4 NE/4	6	05	09E	51.67	17.25	1.12	9.03	0.15	9.08	7.97	0.43	3.15	0.14
MK870973	BASALT OF ICE CAVES	NE/4 NW/4	0	06	09E	49.69	15.77	1.54	12.07	0.19	9.88	7.01	0.37	3.29	0.18
MK870974	BASALT OF INDIAN VIEWPOINT	SE/4 NW/4	36	07	08E	53.14	16.10	1.11	7.21	0.12	8.36	7.98	1.75	3.79	0.44
MK870975	BASALT OF LONE BUTTE	SE/4 NW/4	31	07	07E	52.45	16.95	1.39	8.07	0.14	8.49	7.61	1.10	3.48	0.32
MK870976	BASALT OF BURNT PEAK	NW/4 SE/4	31	07	7.5E	49.26	18.30	1.05	9.82	0.16	10.38	7.68	0.22	3.03	0.10

Table 4. Trace elements data for Quaternary volcanic rocks in the Mount Adams and Hood River 1:100,000 quadrangle. All analyses by XRF, Washington State University. Trace elements in parts per million.

Sample	Unit	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn
MK8887	BASALT OF BURNT PEAK	98	232	33	192	82	6	299	93	23	7.9	16	59	79
MK8888	BASALT OF THOMAS LAKE	107	230	35	190	59	3	309	92	22	6.4	20	68	74
MK8889	BASALT OF BURNT PEAK	99	199	31	161	52	4	253	87	22	7.9	19	73	72
MK88810	BASALT OF TROUT LAKE CREEK	56	160	33	174	62	4	323	89	21	6.9	18	39	66
MK88811	ANDESITE OF MEADOW CREEK	123	198	24	147	164	10	544	150	20	17.9	18	72	75
MK88813	BASALT OF TILLICUM CREEK	143	303	36	205	23	5	285	98	23	9.5	14	62	72
MK88814	BASALT OF TILLICUM CREEK	130	274	36	207	63	4	281	107	27	8.5	18	74	73
MK88815	BASALT OF TWIN BUTTE (WEST)	81	212	31	202	208	11	504	138	24	9.3	18	61	84
MK88816	ANDESITE OF BLACK CREEK	160	214	20	148	371	14	964	171	17	8.5	19	69	90
MK88818	ANDESITE OF BLACK CREEK	101	154	18	140	238	12	654	145	17	11.4	20	50	82
MK88820	ANDESITE OF JUICE CREEK	145	237	25	171	423	19	775	162	20	10.0	20	66	87
MK88822	ANDESITE OF JUICE CREEK	146	164	17	134	399	20	861	164	16	14.6	19	62	78
MK88823	BASALT OF MOSQUITO CREEK	148	363	31	200	257	10	594	160	23	25.0	19	66	83
MK88824	BASALT OF SAWTOOTH MOUNTAIN	135	227	27	168	331	16	702	151	19	9.2	19	34	91
MK88826	BASALT OF RED LAKE	158	235	27	165	501	16	1017	188	21	14.8	19	38	87
MK8891	BASALT OF INDIAN HEAVEN	60	158	32	180	117	10	318	115	23	9.4	16	49	79
MK8893	BASALT OF SHEEP LAKES	88	164	21	160	265	16	558	166	21	23.4	22	51	88
MK8894	BASALT OF ICE CAVES	70	196	35	184	71	5	267	93	22	7.3	18	73	88
MK8895	BASASLT OF LITTLE GOOSE CREEK	148	285	30	176	246	17	602	166	21	28.3	17	37	82
MK870968	BASALT OF THE WART	137	203	20	133	267	10	673	149	18	12.9	19	28	77
MK870969	BASALT SOUTH OF THE WART	97	167	23	159	255	13	547	162	21	22.9	19	60	83
MK870970	ANDESITE OF FORLORN LAKE	58	74	18	106	285	11	634	153	15	11.5	21	56	78
MK870971	BASALT OF LAKE COMCOMLY	67	162	35	190	149	11	364	122	25	10.7	15	64	82
MK870972	BASALT OF DRY CREEK	101	247	32	179	93	8	325	101	21	5.9	16	51	74
MK870973	BASALT OF ICE CAVES	59	204	33	220	52	6	259	106	25	8.3	19	81	92
MK870974	BASALT OF INDIAN VIEWPOINT	155	302	26	174	515	25	994	196	18	8.9	20	56	79
MK870975	BASALT OF LONE BUTTE	141	253	26	165	221	16	544	149	18	19.1	17	64	78
MK870976	BASALT OF BURNT PEAK	102	170	36	166	19	4	244	83	21	5.6	15	77	70

Figure 1. The southwest corner of the Mount Adams 1:100,000 Geologic Map (Korosec, 1987a), showing the northern part of the Indian Heaven volcanic field.

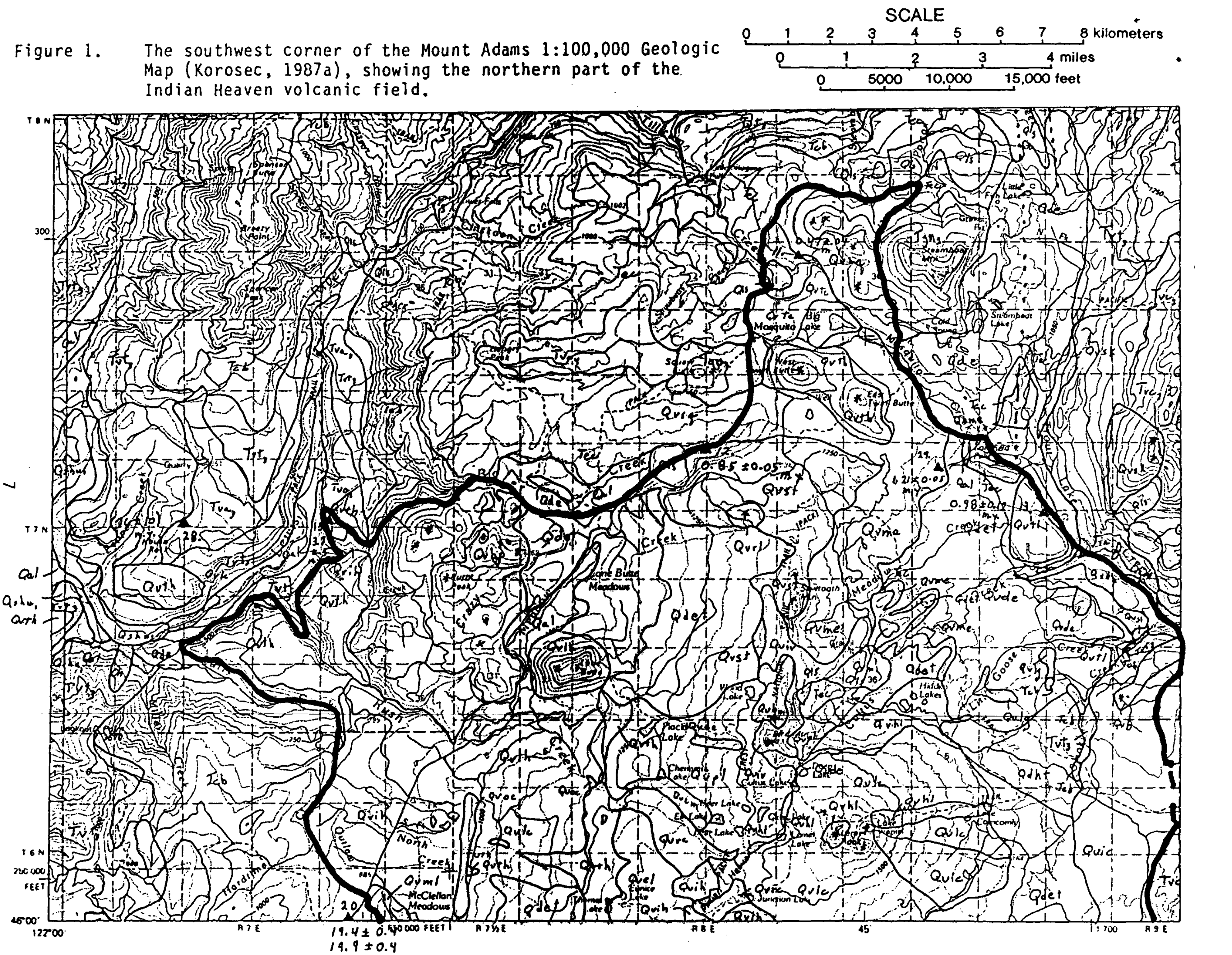
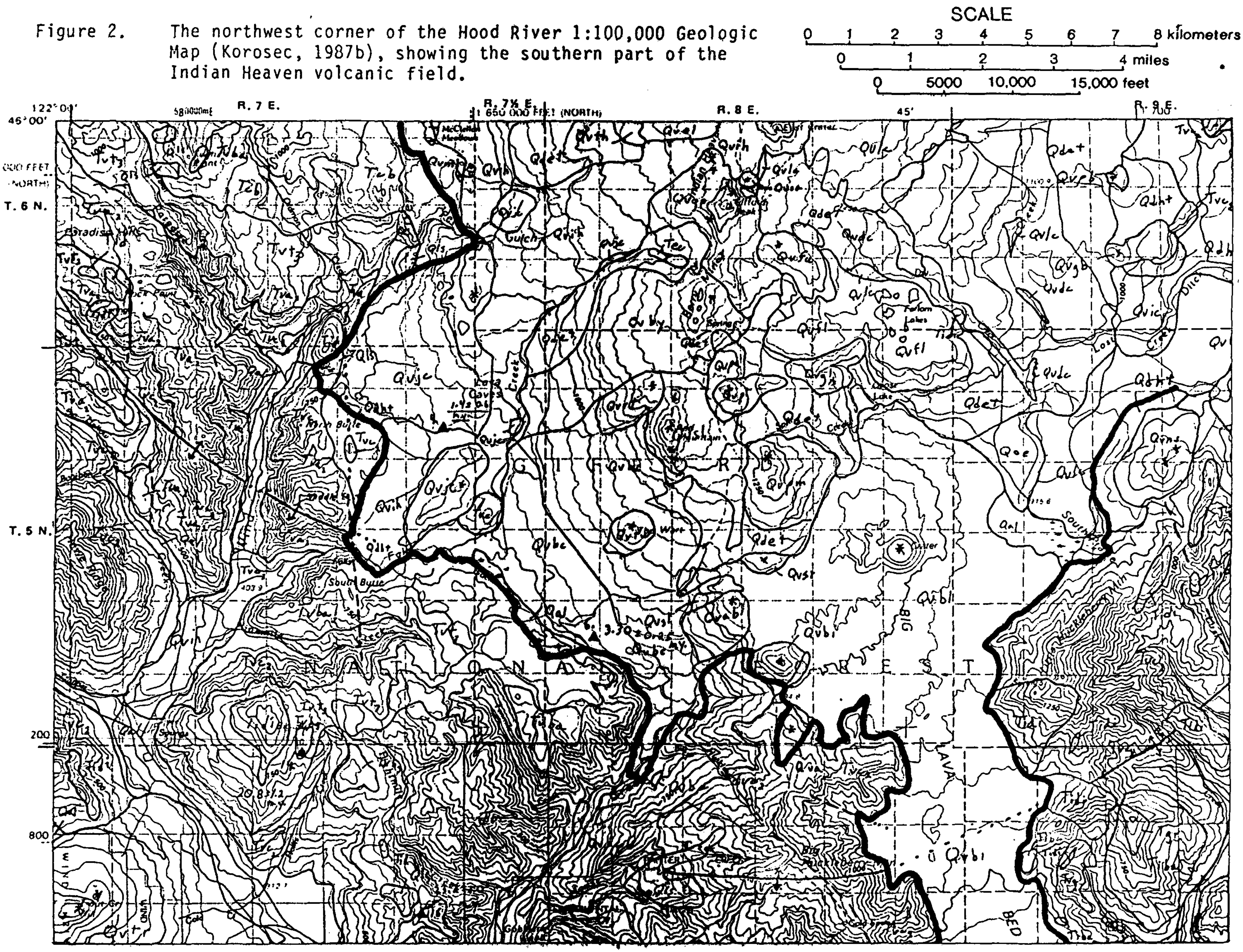


Figure 2. The northwest corner of the Hood River 1:100,000 Geologic Map (Korosec, 1987b), showing the southern part of the Indian Heaven volcanic field.



Department of Geology and are presented in Tables 3 and 4. This represents 22 of the 47 different named units in the field (see Figures 1 and 2 and the Unit Descriptions).

Table 5 contains a list of estimated flow volumes for all named flows of the Indian Heaven volcanic field (Hammond, written commun., 1983). The values have been modified since being reported in Hammond and Korosec (1983). The volume figures are still quite approximate, due to (a) the fact that many of the flows are concealed by younger flows, (b) uncertainties about the surface relief below the flows, and (c) errors associated with estimating original flow volumes where substantial glacial erosion may have taken place.

A preliminary time-stratigraphic correlation diagram has been constructed using selective age dates and stratigraphic relationships between the flows and glacial units (Figure 3). Correlation of the glacial units with named alpine glaciations is tentative.

In addition, copies of the geochemical tables for Indian Heaven flows originally presented as Tables 1, 2, 3, 4, and 8 in Hammond and Korosec (1983) are presented in Appendix A. Geochemistry from Hammond (written communication, 1985) is given in Appendix B.

UNIT DESCRIPTIONS FOR INDIAN HEAVEN LAVA FLOWS AND CINDER CONES

The following descriptions have been modified from Korosec (1987a and Korosec (1987b). The primary sources of the information are unpublished reports and field trip guides from Paul Hammond, Portland State University. Symbols preceding the unit names are from the 1:100,000 geologic maps of Hood River and Mount Adams (Korosec, 1987a; 1987b). Portions of these maps are presented in Figures 1 and 2.

Qvbl

Basalt of Big Lava Bed (Holocene)--Multiple dark-gray, vesicular to dense, phyric olivine basalt flows (Hammond, written commun., 1983). Flows are 0.5-9 m thick, blocky jointed, with slab pahoehoe to scoriaceous tops, with pits 2-6 m deep and wide, furrowed pressure ridges 6-12 m high, fractures up to 5 m wide, and sinuous channels up to 14 m deep and 30 m wide. The lava was erupted as sheet flows, inflated by internally fed lava. The flows cover the valley floor south of Indian Heaven, extending for 59 km^2. The total volume is about 0.9 km^3. A cone near the north center of the bed is 300 m high, with a crater at the top 195 m wide and 66 m deep. Scoriaceous tephra from this crater formed a blanket up to 3 m thick, extending 8 km east of the cone. The tephra overlies pumice of the S-tephra of Mount St. Helens (13,500 yr old); carbonized leaves underlying the Big Lava tephra give a ^{14}C age of 8,200 ± 100 yr b.p. (Hammond and Korosec, 1983).

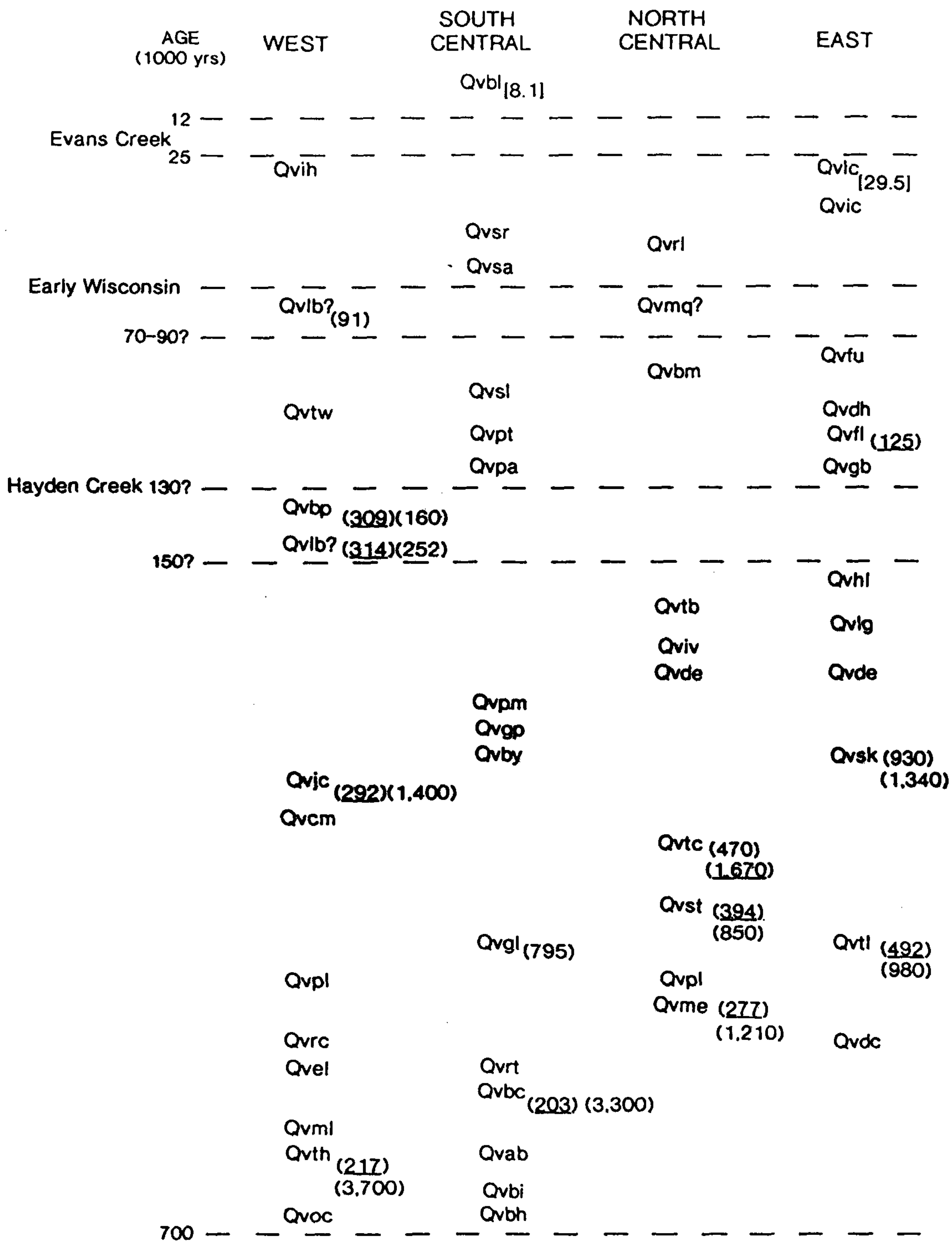


Figure 3. Time-stratigraphic correlation diagram for Indian Heaven volcanic rocks. Ages from K-Ar dating are shown in parentheses with the new dates underlined, and ^{14}C dates are shown in brackets (in thousand of years).

Qvih

Basalt of Indian Heaven--Light-gray, abundantly phyric, olivine basalt (Hammond, written commun., 1983). Phenocrysts consist of randomly oriented plagioclase crystal plates, isolated glomerocrysts of radiating plagioclase plates, and olivine. The groundmass is diktytaxitic, with plagioclase, olivine, and opaque minerals. The basalt forms blocky joined pahoehoe lava flows 1-3 m thick, with 1-3-m-thick interbeds of scoria. Numerous flows erupted from a bocca on the west side of the 120 m high East Crater, and flowed down the west slope, reaching the upper Wind River valley. The flows have a cumulative maximum thickness of 24 m and a total volume of about 0.5 km^3. The age is late Pleistocene, with the East Crater activity post-dating the basalt of Lake Comcomly, a 29,000-yr-old flow (Hammond, written commun., 1985).

Qvlc

Basalt of Lake Comcomly--Dark-gray, sparsely phyric olivine basalt (Hammond, written commun., 1983). Glomerocrysts of plagioclase phenocrysts surrounding olivine phenocrysts are in a fine-grained groundmass of plagioclase, olivine, and opaque minerals. The basalt forms pahoehoe lava flows, 0.5-12 m thick, with scoriaceous margins, pillow lava, breccia, and abundant tumuli. The cumulative thickness is 2-30 m, and the estimated volume is about 1.3 km^3. The source of the lava was the southeast crater of the Lemei Rock volcano (north of the map area), marked by a 120-m-high scoria and spatter cone. Flows descended the east and west "flanks" of Indian Heaven, partially covering the broad slope formed by the basalt of Ice Caves (Qvic). The eruptions occurred in late Pleistocene time, probably about 30,000 years ago, based on ^{14}C dating of carbon fragments immediately below finally layered basalt tephra from the Lake Comcomly eruption.

Qvic

Basalt of Ice Caves--Gray, abundantly phyric, olivine basalt (Hammond, written commun., 1983). In thin section, phenocrysts of plagioclase and olivine are in a diktytaxitic, holocrystalline groundmass of plagioclase, olivine, and opaque minerals. The plagioclase phenocrysts are generally glomerocrysts of radiating laths. The basalt forms blocky jointed pahoehoe lava flows 0.5-6 m thick. They were erupted from the crater at Lake Wapiti of Lemei Rock volcano and flowed down the east flank. One lobe flowed northeast, up Trout Lake Creek. Most of the lava went south and east into the White Salmon River canyon at Trout Lake and down the canyon at least 43 km to Husum. The flow is 10-12 m thick, and its volume is about 1.3 km^3. It is younger than Hayden Creek glaciation (130,000-150,000 yr b.p.) but older than Evans Creek glaciation (22,000-14,000 yr b.p.).

Qvsr

Basalt cone southeast of Red Mountain--Black to red scoriaceous tephra (Hammond, written commun., 1983). The tephra forms a cone 70 m high on the west side of the Big Lava Bed. The cone has an approximate volume of 0.03 km^3. The unit is of late Pleistocene age, probable not much older than the Evans Creek Drift which mantles much of the north side of the cone. It may have been the source of valley-filling basalts, including the basalt of Little White Salmon (Qvlw) now mostly covered by basalt of Big Lava Bed (Qvbl).

Qvsa

Basalt of Sahalee Tyee--Dark-gray, moderately phyric, olivine basalt (Hammond, written commun., 1983). Basaltic tephra, consisting of coarse scoria and bombs, form a broad cone, 12 m high, north of Gifford Peak and Blue Lake. The cone has a central crater 365 m in diameter, partially filled by a small lake named Sahalee Tyee. A single, small lava flow makes up a part of the cone. The unit is of late Pleistocene age, younger than Hayden Creek alpine glaciation (130,000-150,000 years ago).

Qvrl

Basalt of Red Lake--(Basaltic cone northwest of Sawtooth Mountain, Hammond, written commun., 1983). Dark-gray, sparsely phyric, olivine basalt. The basalt consists of scoria, spatter, and aa lava lenses forming a broad craterless cone 12 m high, with an approximate volume of 0.004 km^3. The cone has been partially eroded during Evans Creek glaciation, from a glacier heading on Sawtooth Mountain. The unit is of late Pleistocene age.

Qvmq

Basalt of Mosquito Creek (also known as basalt west of Steamboat Mountain)--Olivine basalt flows and scoria (Hammond, 1980). Flows and scoria form three cones on the lower west flank of Steamboat Mountain with a total volume of about 0.44 km^3. The surfaces of the flows are free of glacial deposits, suggesting an age younger than Evans Creek alpine glaciation, less than 14,000 to 22,000 yr b.p., but the weathering zone suggests a somewhat older age.

Qvfu

Upper andesite of Forlorn Lakes--Light-gray, sparsely phyric two pyroxene-olivine andesite flows and flow breccia (Hammond, written commun., 1983). The andesite consists of plagioclase, olivine, augite, and hypersthene phenocrysts in a dense, flow-layered groundmass. Blocky lava flows 15-30 m thick are separated by breccia zones 30-40 m thick. The total thickness is 60-90 m, and the approximate volume is 0.12 km^3. The lava was derived from a low scoria and breccia cone just east of Gifford Peak. The stratigraphic position of the unit suggests a probable late Pleistocene age.

Qvbm

Basalt of Bird Mountain--Medium-gray, abundantly phyric, olivine basalt (Hammond, written commun., 1983). The basalt forms aa lava flows 1.5 m thick, with 10-20 cm interbeds of scoria. They were erupted from a scoria cone on the northern peak of Bird Mountain. The cumulative thickness is 50-60 m, forming an estimated total volume of 0.29 km^3. The unit is of middle or late Pleistocene age.

Qvsl

Basalt of Sheep Lakes--Medium-gray, moderately phyric olivine basalt (Hammond, written commun., 1983). The basalt forms blocky jointed, 2-4-m-thick pahoehoe and aa lava flows, separated by scoria interbeds 0.2-0.5 m thick. The total thickness ranges from 5 to 25 m, and the volume is approximately 0.08 km^3. The flows were erupted from the east base of Red Mountain in the late Pleistocene.

Qvtw

Basalt of The Wart--Gray, sparsely phyric, olivine basalt (Hammond, written commun., 1983). Phenocrysts of plagioclase and olivine are in a partly glassy, vesicular to densely crystalline groundmass. The basalt forms a saggy pahoehoe lava flow 1-5 km thick, and a 145 m high craterless cone of interlayered scoria, lithic fragments, and spatter. The total volume is estimated to be 0.04 km^3. The northeastern flank of the cone is mantled by 2 m of till from Evans Creek alpine glaciers. The probable age is late Pleistocene.

Qvpt

Basalt of Petite Mountain (basalt northeast of Red Mountain)-- Gray olivine basalt (Hammond, written commun. 1983. The flows were extruded from the eastern side of the butte 1 km northeast of Red Mountain. The butte is locally known as Petite Mountain, but the name does not appear on the most recent U.S. Geological Survey quadrangle maps.

Qvdh

Basalt of Dead Horse Creek--Dark- to medium-gray, abundantly phyric olivine basalt (Hammond, written commun., 1983). Phenocrysts of plagioclase, olivine, and hypersthene are in a fine-grained groundmass. The basalt forms a blocky intracanyon lava flow, 6-35 m thick. It's total volume is about 0.03 km^3. The age of this unit is late Pleistocene, younger than the Hayden Creek alpine glaciation (less than 130,000 yr b.p.).

Qvfl

Andesite of Forlorn Lakes--Light-gay, sparsely phyric two pyroxene-olivine andesite flows and flow breccia (Hammond, written commun., 1983). The andesite consists of phenocrysts of plagioclase, olivine, augite, and hypersthene in a dense, flow-layered groundmass. It forms block lava flows, 10-30 m thick, with flow-folded interiors. Individual flows are separated by breccia zones up to 30 m thick, with a cumulative thickness of about 100 m and total volume of about 1.1 km^3. The flows were erupted from a vent east of Gifford Peak in the late Pleistocene. They are partially eroded by alpine glaciers and are overlain by the andesite of upper Forlorn Lake (Qvfu). The K-Ar age of 125,000 ± 14,000 yr b.p. from this study seems to be a reasonable determination.

Qvgb

Basalt of Grouse Butte--Medium-gray, moderately phyric olivine basalt flows and cone (Hammond, written commun., 1983). Flows are blocky jointed pahoehoe lava, 2-6 m thick, with a cumulative thickness of 6-10 m and an estimated volume of 0.009 km^3. They were erupted from the northeast base of the glacially molded, craterless scoria cone at Grouse Butte, about 5 km northwest of Mann Butte. The cone is 100 m high and has a diameter of about 640 m. The basalt is of probable middle to late pleistocene age.

Qvbp

Basalt of Burnt Peak--Medium-gray, moderately phyric, olivine basalt (Hammond, written commun., 1983). Phenocrysts of plagioclase and olivine are set in fine grained groundmass. The basalt formed subglacial moberg deposits of interstratified pillow lava flows and thin to thick-bedded palagonitic hyaloclastic breccia and tuff (Pederson, 1973). At least six separate vents form topographic highs within the Crazy Hills, the most prominent of which is Burnt Peak. The unit has a total thickness of 60-100 m and an estimated volume of 1.71 km^3. It was probably formed during the Hayden Creek alpine glaciation between about 30,000 and 150,000 yr b.p. while a previous K-Ar age date of 160,000 ± 38,000 yr b.p. supports this, the new K-Ar date of 309,000 ± 75,000 yr b.p. brings this interpretation into question.

Qvlb

Basalt of Lone Butte--Medium-gray, moderately phyric, olivine basalt (Hammond, written commun., 1983). Lone Butte is a 400 m high tuya "composed of foreset-bedded pillow-lava breccia with interstratified, thin- to thickly-bedded, locally palagonized hyaloclastic breccia and tuff, overlain by 73 m of subaerial scoriaceous lava, and capped by a 60 m dissected cone of scoriaceous agglutinate" (Hammond, written commun., 1983). The total volume of Lone Butte is about 0.33 km^3. It was probably erupted either during the Hayden Creek alpine glaciation (130,000-150,000 yr b.p.) or during an alpine glaciation corresponding to early Wisconsin time (70,000 - 90,000 yr b.p.). K-Ar dates have a wide range of results, with 91,000 ± 10,000 and 252,000 ± 7,000 yr b.p. determined previously, and 314,000 ± 54,000 yr b.p. determined in this study Lone Butte may be related to the subglacial mobergs of the basalt of Burnt Peak (Qvbp).

Qvhl

Basalt of Hidden Lakes--Light- to medium-gray, moderately phyric, olivine basalt (Hammond, written commun., 1983). Phenocrysts of plagioclase and olivine are set in a dense, very fine-grained granular groundmass. The basalt forms aa and pahoehoe lava flows, 1-8 m thick, with 0.5-3 m thick scoriaceous zones separating flows. The total thickness is 60-75 m, with an estimated volume of 5.2 km^3 (includes the Basalt of Little Goose Creek). Most of the Lemei Rock volcano consists of the basalt of Hidden Lake. The unit has a probable age of late Pleistocene, suggested by its stratigraphic position.

Qvlg

Basalt of Little Goose Creek--Light-gray, sparsely phyric, olivine basalt (Hammond, written commun., 1983). Olivine phenocrysts are set in a pilotaxitic groundmass of primarily plagioclase and olivine. The basalt forms blocky jointed lava flows, 4-12 m thick, with scoriaceous zones separating individual flows. The maximum cumulative thickness is 73 m. The volume has been included in the calculation for the volumes of the Basalt of Hidden Lakes. This unit forms the basal part of the Lemei Rock volcano and is stratigraphically confined to be of late Pleistocene age. A previously determined K-Ar age date of 28,000 $\pm$ 400,000 yr b.p. is of questionable value.

Qvpa

Andesite of Petite Mountain (andesite northeast of Red Mountain)--Light-gray, aphyric olivine andesite (Hammond, written commun., 1983). Blocky to platy jointed aa lava flows were extruded from the base of an irregular shaped, craterless, scoria cone, 135 m high and 1,300 m long. Individual flows are 2-3 m thick and have a cumulative thickness of 10 m. The volume is estimated to be about 0.03 km^3. These flows erupted in the late Pleistocene, probably after Hayden Creek alpine glaciation (130,000-150,000 years ago) but before Evans Creek alpine glaciation. The unit's informal name is derived from a hill northeast of Red Mountain which is locally called Petite Mountain, but the name does not appear on the most recent U.S. Geological Survey quadrangle map.

Qvtb

Basalt of Twin Buttes--Medium- to dark-gray, phyric, olivine basalt (Hammond, 1980). Vesicular to scoriaceous, blocky jointed flows form the summits of East Twin Butte and West Twin Butte. The total cumulative thickness of the flows is 30-120 m. The flanks of the buttes are composed of a high percentage of cinders. The unit's stratigraphic position suggests a middle to late Pleistocene age.

Qviv

Basalt of Indian Viewpoint--Light- to medium-gray, abundantly phyric, olivine basalt (Hammond, written commun., 1983). Phenocrysts of plagioclase, olivine, and minor augite are in a very fine grained, pilotaxitic to equigranular groundmass. The basalt forms thick, scoria-fed aa lava flows 1.5-4.0 m thick, with 15-150 cm thick interbeds of scoria. The flows reach a cumulative total thickness of 60 m, and have a volume of about 4.5 km^3. They erupted from a vent at Bird Mountain in the late Pleistocene, probably before Hayden Creek alpine glaciation.

Qvde

Basalt of Deep Lake--Light-gray, moderately phyric augite-plagioclase-olivine basalt (Hammond, written commun., 1983). Phenocrysts are set in a fine-grained granular groundmass. The basalt forms blocky jointed flows, 6-25 m thick, with scoria interbeds up to 50 cm thick. Two flows are preserved on the west slope of Bird Mountain. They were erupted from a vent on the southeast flank of Bird Mountain. In addition, three flows erupted from this vent flowed eastward across the north slope of the Lemei Rock volcano into the Trout Lake Creek canyon. These flows have a maximum thickness of 25 m, and the cumulative volume of the unit is about 1.3 km^3. The basalt of Deep Lake has a probable middle or late Pleistocene age, suggested by its stratigraphic position.

Qvpm

Basalt of Papoose Mountain (basalt southeast of Red Mountain)--Medium-gray, moderately phyric, olivine basalt (Hammond, written commun., 1983). Phenocrysts of plagioclase and olivine are in a fine-grained groundmass. The basalt forms an eroded, craterless cone of agglutinated scoria, 195 m high and 2,000 m wide. Blocky jointed pahoehoe lava flows, 2-6 m thick, partially cover the eastern and southern slopes. The individual flows are commonly separated by scoria interbeds 0.2-0.5 m thick. The cumulative thickness is 75 m, and the estimated volume is 2.7 km^3. The unit is probably of middle Pleistocene age. The unit's informal name is derived from the butte 2 km southeast of Red Mountain, known locally as Papoose Mountain, but the name does not appear on the most recent U.S. Geological Survey quadrangle maps.

Qvgp

Basalt of Gifford Peak--Light- to medium-gray phyric olivine basalt flows (Hammond, written commun., 1983). In thin section, phenocrysts of plagioclase and olivine are set in a fine-grained, flow-banded groundmass. The basalt forms blocky to platy- jointed lava flows 1-12 m thick, commonly with scoria interbeds up to 0.5 m thick, with a cumulative thickness of 90 m and a volume of approximately 1.9 km^3. The flows were probably erupted from a zone of east-west-trending dikes on the north side of Gifford Peak. It has a probable middle Pleistocene age, suggested by its stratigraphic position.

Qvby

Basalt of Berry Mountain--At least five lava flows erupted from vents near Gifford Peak and on Berry Mountain (Hammond, written commun., 1983). From oldest to youngest, they are light- to dark-gray, sparsely to moderately phyric olivine basalt, augite-olivine basalt, hornblende-plagioclase andesite, augite plagioclase-olivine basalt, and hornblende-augite-olivine basaltic andesite. The flows are blocky and platy jointed, 1-12 m thick with a cumulative thickness of 50-100 m. The total volume is estimated to be about 1.6 km^3. The Basalt of Berry Mountain is of middle or late Pleistocene age, probably erupted before the Hayden Creek alpine glacial periods, between about 130,000 yr b.p.

Qvsk

Basalt west of Skull Creek--Dark-gray, moderately phyric, olivine basalt (Hammond, written commun., 1983). Olivine phenocrysts are set in a dense, very fine grained groundmass. The basalt forms blocky jointed to columnar jointed lava flows along Trout Lake Creek. The total cumulative thickness is 35 to 75 m and estimated volume 0.8 km^3. The source vents for the flows form a ridge on the west side of Sleeping Beauty. A whole-rock K-Ar age date of 1.34 $\pm$ 0.02 m.y. b.p. was previously determined for the unit (Hammond and Korosec, 1983), but this flow is believed to be significantly younger than this.

Qvjc

Andesite of Juice Creek--Light-gray, sparsely phyric augite basaltic andesite and augite-olivine basaltic andesite (Hammond, written commun., 1983). The groundmass is dense, fine grained, and equigranular, with flow-layered plagioclase laths. The lava flows are platy, blocky, and columnar jointed and are 4-60 m thick. The estimated volume is 2.0 km^3. A broad, dissected shield volcano, about 170 m high, and about 5 km west of Berry Mountain, marks the source of most of the lava. A possible second vent is located on a butte about 5 km west-southwest of Red Mountain. A whole-rock K-Ar age date of 1.40 $\pm$ 0.06 m.y.b.p. was determined for this unit (Hammond and Korosec, 1983), but the flows are believed to be significantly younger. A K-Ar date of 292,000 $\pm$ 33,000 yr b.p. determined for this study is likely to be closer to the actual age.

Qvcm

Basalt of Chenamus Lake--A small olivine basalt flow southwest of Bird Mountain atop the basalt of Placid Lake. The source of this flow is not known.

Qvtc

Basalt of Tillicum Creek--Olivine basalt (Hammond, written commun., 1985). The basalt forms pillowed lava flows and hyaloclastites. It is the most mafic unit of the Indian Heaven volcanic field. The flows may have been erupted near the margin of a glacier originating at the topographically high "plateau" of Indian Heaven and possibly extending into the Lewis River drainage. The cumulative flows have an average thickness of 60 m and a total volume of about 0.31 km^3. A previously determined whole-rock K-Ar age date of 470,000 ± 40,000 yr b.p. (Hammond and Korosec, 1983), suggests that the glaciation may coincide with Wingate alpine glaciation. A new K-Ar date of 1.67 ± 0.23 m.y. b.p. is probably much to old, and can be discounted because of its low K_2O and low percentage radiogenic Ar.

Qvst

Basalt of Sawtooth Mountain (Basalt of Surprise Lakes)--Light- gray, moderately phyric, olivine basalt (Hammond, written commun., 1983). The basalt consists of phenocrysts of plagioclase and olivine in a dense, very fine-grained pilotaxitic to equigranular groundmass. The lava flows are blocky to slabby jointed, 1-4 m thick, with scoria interbeds 20-50 cm thick. The greatest cumulative thickness is 79 m, and the total volume is estimated to be 3.4 km^3. The Sawtooth Mountain volcano was the source of these flows. A whole-rock K-Ar age date of 850,000 ± 50,000 yr. b.p. was previously determined for this unit (Hammond and Korosec, 1983). A new K-Ar age of 394,000 ± 39,000 yr b.p. determined by this study is probably closer to the actual age.

Qvgl

Basalt of Goose Lake--Light- to medium-gray, fine-grained, phyric olivine basalt (Hammond, written commun., 1983). The basalt forms blocky to platy-jointed pahoehoe flows, 2-10 m thick, and has local interbeds of airfall scoria up to 2 m thick. The cumulative thickness is 46 m, and the volume is approximately 1.8 km^3. The flows overlap a 120-m-high scoria cone exposed in Spring Camp Creek northwest of Goose Lake. The age of the unit is probably middle Pleistocene, suggested by its stratigraphic position. A previously determine of K-Ar age date of 800,000 ± 28,000 yr b.p. is probably to old by about 200,000-400,000 years.

Qvtl

Basalt of Trout Lake Creek--Light-gray, moderately phyric, augite-olivine basalt (Hammond, written commun., 1983). Phenocrysts of plagioclase, olivine, and augite are set in a diktytaxitic groundmass. The basalt forms pahoehoe lava flows 1-10 m thick with no interbeds. The source of the flows is unknown. The flows have a maximum cumulative thickness of 35 m and an approximate preserved volume of 1.63 km^3. A previously determined whole-rock K-Ar age date for the unit was 980,000 ± 120,000 yr b.p. (Hammond and Korosec, 1983), but the remanent magnetic polarity is normal. The new K-Ar age date of 492,000 ± 84,000 yr b.p. determined for this study is more likely closer to the actual age of this unit.

Qvpl

Basalt of Placid Lake--Light- to medium-gray, moderately phyric, olivine basalt (Hammond, written commun., 1983). Phenocrysts of olivine are in a fine grained granular groundmass of plagioclase and olivine. The basalt forms blocky jointed lava flows 0.5-8 m thick, with a maximum cumulative thickness of 155 m and an approximate volume of 5.8 km^3. The flows were erupted from a zone of dikes west of Bird Mountain. The stratigraphic position of this unit suggests a middle Pleistocene age.

Qvme

Andesite of Meadow Creek--Medium-gray, moderately phyric, olivine basaltic andesite (Hammond, written commun., 1983). Phenocrysts of plagioclase and olivine are set in a dense, very fine grained pilotaxitic groundmass. The basaltic andesite forms blocky flows, 2-13 m thick, with a total cumulative thickness of 122 m, and an estimated volume of 3.4 km^3. The unit underlies a part of Sawtooth Mountain, the source of the basalt of Sawtooth Mountain, previously K-Ar dated to be 850,000 $\pm$ 50,000 yr b.p. and dated for this study to be 394,000 $\pm$ 39,000 yr. b.p. A previous whole-rock K-Ar age date of 1.21 $\pm$ 0.05 m.y. b.p. has been reported for this flow by Paul Hammond in a 1985 field trip guide to the Indian Heaven volcanic field, but this age is probably too old, since the flow has normal remanent magnetic polarity. A new K-Ar age date of 277,000 $\pm$ 20,000 yr b.p. was determined for this study, and may be closer to the actual age of the unit.

Qvrc

Basalt of Rush Creek--Medium-gray, sparsely to moderately phyric, augite-olivine basalt (Hammond, written commun., 1983). Pahoehoe lava flows, 1-10 m thick, are commonly separated by interbeds of scoria 0.2-2 m thick. The flows have a total maximum thickness of 370 m and an estimated volume of 4.75 km^3. The exact source of these flows is unknown, probably concealed by the younger flows near the center of the Indian Heaven volcanic field. The basalt of Rush Creek is petrographically and morphologically similar to and may correlate with the basalt of Dry Creek (Qvdc). The unit's stratigraphic position suggests a middle Pleistocene age.

Qvdc

Basalt of Dry Creek--Medium-gray, vesicular to dense, sparsely to moderate phyric augite-olivine basalt. Numerous pahoehoe flows 1-10 m thick, with blocky jointing, are commonly separated by 0.2-2-m-thick interbeds of scoria and have a total maximum thickness of 370 m. The volume is approximately 9.2 km^3. The source is unknown, but a dike at south East Crater is a possibility. The basalt of Dry Creek is similar to the basalt of Rush Creek (Qvrc) and may be its correlative. The stratigraphic position of the flows suggests a probable middle Pleistocene age.

Qvel

Andesite of Eunice Lake--Light- to medium-gray vesicular to dense phyric olivine basaltic andesite and aphyric andesite. Phenocrysts of plagioclase and olivine are in a fine-grained flow-layered groundmass. Numerous blocky to platy-jointed flows 1-12 m thick are commonly separated by scoria interbeds of 0.5 m thick, having a maximum cumulative thickness of 140 m, and have an approximate volume of 2.0 km^3. The flows may have erupted from a zone of east-west-trending dikes on the north side of Gifford Peak. The stratigraphic position of the flows suggests a probable middle Pleistocene age.

Qvrt

Andesite of The Race Track--Medium-gray, sparsely phyric, olivine andesite (Hammond, written commun., 1983). Phenocrysts of olivine and plagioclase are in a fine-grained groundmass. The andesite forms slabby lithic clasts in agglutinated lithic scoria surrounding a denuded plug or dome west of The Race Track on the northwest side of Red Mountain. The unit has a total thickness of 75 m. Its age is unknown, but may be related to the andesite of Black Creek (Qvbc).

Qvbc

Andesite of Black Creek--Medium-gray, sparsely phyric plagioclase-olivine andesite and basaltic andesite (Hammond, written commun., 1983). Slabby, blocky to columnar-jointed aa and block lava flows form a broad field fanning to the south and west from a buried or eroded source near Red Mountain. Individual flows are 2-18 m thick, with a cumulative thickness of 60-120 m. The volume is estimated to be 8.16 km^3. A whole-rock K-Ar age date of 3.3 $\pm$ 0.25 m.y. b.p. (Hammond and Korosec, 1983) is probably too old, suggested by normal remanent magnetism and a lack of reversed magnetic flows stratigraphically above these flows. A K-Ar age date of 203,000 $\pm$ 36,000 yr b.p. was determined for this study, but this value is probably to young by a few hundred thousand years.

Qvml

Basalt of McClellan Meadows--Medium-gray phyric olivine basalt. Phenocrysts of plagioclase and olivine are in a diktytaxitic groundmass of plagioclase, olivine, and clinopyroxene. The flows form part of the western margin of the Indian Heaven volcanic field and are partially lapped by flows of the basalt of Indian Heaven (Qvih). The source and age of the McClellan Meadows flows are not known.

Qvab

Basalt of Alice Butte--Gray, phyric olivine basalt (Hammond, written commun., 1983). Olivine phenocrysts are set in a fine- grained granular groundmass. The flows form a 122-m-high butte south of Red Mountain. The unit's informal name is derived from a hill in sec. 28, T. 5 N., R. 8 E., which is locally called Alice Butte; the name does not appear on the most recent U.S. Geological Survey quadrangle maps. The butte is a volcanic center, with an age stratigraphically confined to be 150,000-500,000 years old.

Qvbi

Basaltic andesite of Bill Butte--Dark-gray phyric olivine basaltic andesite. Phenocrysts of olivine and rare xenocrysts of quartz are in a fine-grained crystalline groundmass. The flow forms the cone southwest of the Big Lava Bed crater. The unit's informal name is derived from a hill in sec. 27, T. 5 N., R. 8 E., which is locally called Bill Butte, but the name does not appear on the most recent U.S. Geological Survey maps.

Qvbh

Andesite north of Big Huckleberry Mountain--Dark-gray quartz-olivine basaltic andesite flow (Wise, 1961). Phenocrysts of olivine and xenocrysts of quartz are in a fine-grained groundmass of plagioclase, olivine, and opaque minerals. The massive basaltic andesite has no flow tops or bottoms exposed in the limited outcrops. Wise (1961) believed that the rounded hill represented an eroded flow remnant, but Hammond (1980) maps the hill as a vent. The basaltic andesite may be the same as or related to the basaltic andesite of Bill Butte (Qvbi), 1.5 km to the north. No direct age control exists for these flows, but the thick soil cover suggests an early middle Pleistocene age.

Qvth

Basalt of Thomas Lake--Light-gray, abundantly phyric, augite- olivine basalt (Hammond, written commun., 1983). Phenocrysts consist of randomly oriented platelets of plagioclase and granular augite and olivine, in a diktytaxitic groundmass. The basalt forms blocky jointed pahoehoe lava flows 1-7 m thick, erupted from fissures at the south end of East Crater. Erosion has partially exposed the dikes. The unit has an average cumulative thickness of 37 m and an estimated volume of 5.0 km^3. The basalt of Thomas Lake is one of the oldest units of the Indian Heaven volcanic field, but may not be as old as some of the age dates indicate. A previously determined whole-rock K-Ar age date of 3.7 +/- 0.5 m.y. b.p. was determined for this unit (Hammond and Korosec, 1983), but is probably much to old, given its normal remanent magnetic polarity. A K-Ar age of 217,000 $\pm$ 122,000 yr b.p. determined for this study is much too young, and is of questionable value because of its low K_2O, low ^{40}Ar, and low percentage of radiogenic Argon.

Qvoc

Basalt of Outlaw Creek--Medium-gray, sparsely phyric, olivine basalt (Hammond, written commun., 1983). Phenocrysts of plagioclase and olivine are in a fine-grained, equigranular groundmass of plagioclase, olivine, and opaque minerals. The basalt forms blocky jointed lava flows 3-8 m thick, separated by scoria interbeds up to 1 m thick. The thickest exposure of the flows is 26 m. The source of the basalt is not known. These flows are stratigraphically the lowest known unit of the

Indian Heaven volcanic field, indicating an early middle Pleistocene age.

DISCUSSION

Age of the Indian Heaven volcanic field

Previously determined age dates have suggested in the past that the Indian Heaven volcanic field may be as old as 3.7 million years, making it one of the longest "active" volcanic fields or piles in the Cascade Range. However, when extensive paleomagnetic studies of 56 individual lava flows (sites) from 23 units were conducted (Mitchell and others, unpublished report, 1988), nearly all were found to be normally magnetized, suggesting that volcanic activity had occurred within the last 730,000 years. The other possibility, that all flows had been erupted during periods of normal magnetism over the last 3 to 4 million years, is statistically unrealistic, since the earth's magnetic field has spent approximately 50 percent of its time in a reverse configuration over that time interval. Only the 4 lowest flows exposed in the eroded core of the Gifford Peak volcano gave reverse remanent magnetic polarity. This suggests that the onset of volcanism at the field was probably very close to 730,000 year ago.

We may have substantial doubts about the accuracy of many of the newly determined K-Ar age dates from this study, but the dominance of relatively young dates (less than 500,000 yr b.p.) among the values would tend to support the interpretation that most of the volcanic field is less than 730,000 years old. Based on these observations and interpretations, a preliminary time-stratigraphic correlation diagram has been constructed, using selective age dates and stratigraphic relationships between the flows and glacial units (Figure 3).

Correlation of the glacial units with named alpine glaciations in Figure 3 is tentative. All age dates, new and old, are listed with the units. This further illustrates the inconsistencies and contradictions brought about by the age date results.

Volume of Indian Heaven and other Quaternary volcanic piles

The total volume of the Indian Heaven flows from Table 5 is 74.7 km^3. This is in the range of volumes of volcanic rocks produced at several of the Cascade Range stratovolcanics, using the estimates of Smith (1989). In fact, Indian Heaven is the third largest quaternary volcanic pile in the state.

Mount Adams has the greatest volume, 200 km^3 formed over the last 500,000 years; Mount Rainier has a total volume of volcanic products of 136 km^3 formed over the last 600,000 yr to 1 m.y.; Mount Baker has produced an estimated 72 km^3 over the past 730,000 years; Glacier Peak produced 29.4 km^3 over the past 300,000 to 400,000 years; and Mount St. Helens has erupted about 78 km^3 over the last 40,000 years. The other

Table 5. Estimated volumes for Indian Heaven flows.

Unit Name	Map Symbol	Volume Estimate (km^3)
Basalt of Big Lava Bed	Qvbl	0.88
Basalt of Indian Heaven	Qvih	0.5
Basalt of Lake Comcomly	Qvlc	1.34
Basalt of Ice Caves	Qvic	1.3
Basalt SE of Red Mountain	Qvsr	0.03
Basalt of Sahalee Tyee	Qvsa	---
Basalt of Red Lake	Qvrl	.004
Basalt of Mosquito Lakes	Qvmq	0.44
Upper Andesite of Forlon Lakes	Qvfv	0.12
Basalt of Bird Mountain	Qvbm	0.29
Basalt of Sheep Lakes	Qvsl	0.08
Basalt of The Wart	Qvtw	0.04
Basalt of Petite Mountain	Qvpt	0.2+
Basalt of Dead Horse Creek	Qvdh	0.03
Andesite of Forlorn Lakes	Qvfl	1.1
Basalt of Grouse Butte	Qvgb	0.009
Basalt of Burnt Peak	Qvbp	1.71
Basalt of Lone Butte	Qvlb	0.33
Basalt of Little Goose Creek	Qvlg	0.2+
Basalt of Hidden Lakes	Qvhl	5.0
Andesite of Petite Mountain	Qvpa	0.03
Basalt of Twin Buttes	Qvtb	0.1
Basalt of Indian Viewpoint	Qviv	4.5
Basalt of Deep Lake	Qvde	1.3
Basalt of Papoose Mountain	Qvpm	2.7
Basalt of Gifford Peak	Qvgp	1.9
Basalt of Berry Mountain	Qvby	1.6
Basalt west of Skull Creek	Qvsk	0.8
Andesite of Juice Creek	Qvjc	2.0
Basalt of Chenamus Lake	Qvcm	---
Basalt of Tillicum Creek	Qvtc	0.31
Basalt of Sawtooth Mountain	Qvst	3.4
Basalt of Goose Lake	Qvgl	1.8
Basalt of Trout Lake Creek	Qvtl	1.63
Basalt of Placid Lake	Qvpl	5.8
Andesite of Meadow Creek	Qvme	3.4
Basalt of Rush Creek	Qvrc	4.75
Basalt of Dry Creek	Qvdc	9.2
Andesite of Eunice Lake	Qvel	2.0
Andesite of The Race Tract	Qvrt	0.05
Andesite of Black Creek	Qvbc	8.16
Basalt of McClellan Meadows	Qvml	0.2+
Basalt of Alice Butte	Qvab	0.1
Basalt of Bill Butte	Qvbi	0.1
Andesite North of Big Huckleberry	Qvbh	0.1
Basalt of Thomas Lake	Qvth	5.0
Basalt of Outlaw Creek	Qvoc	0.2+
Total		74.733 km^3

quaternary volcanic fields in the Cascade Range, Tumac Mountain, King Mountain, an unnamed field north of Mount Adams (consisting of flows near Walupt Lake, Lakeview Mountain, Two Lakes, Spring Creek, and Potato Hill), and the West Crater/Soda Peak field have estimated volumes of 12, 6, 5, and 1.5 km^3 respectively.

Rate of production for the volcanic flows

Using the earlier age date and flow volume data, Hammond (written communication, 1983) estimated that productions rates would calculate to be 52 m^3/day for the period of 3.7 m.y. b.p. to about 500,000 yr b.p., and about 71 m^3/day over the last 500,000 years. Using the new data, and assuming that the onset of volcanism producing the measured flows occurred at about 700,000 yr b.p., very different results were calculated.

For the entire interval, 700,000 yr b.p. to present, approximately 74.7 km^3 of volcanic flows were erupted (table 5), which gives an average production rate of 0.107 km^3/1,000 years, or about 290 m^3/day. For the interval 150,000 yr b.p. to present, 13.60 km^3 were erupted, for an overage production rate of 0.091 km^3/1,000 years, or about 250 m^3/day. From 700,000 yr b.p. to 150,000 yr b.p., 61.13 km^3 erupted, at an average rate of 0.111 km^3/1,000 years, or 305 m^3/day. Given the uncertainty in flow volume measurements and the uncertainty of the 150,000 years time line on the correlation diagram, the differences between early production rates and later rates are insignificant. The implication is that average lava flow production at the Indian Heaven volcanic field may have remained relatively constant over its entire history. When the youngest 3 major flows are examined, with a total volume of 2.72 km^3 erupted since about 30,000 years ago, against, 0.091 km^3/1,000 years, or 250 m^3/day is the average production rate.

Interval (1,000 years)	Volume km^3	Rate km^3/1,000 yr.	Rate m^3/day
0 - 30	2.72	0.091	250
0 - 150	13.60	0.091	250
150 - 700	61.13	0.111	305
0 - 700	74.73	0.107	290

When the average production rate of 0.107 km^3/1,000 years is expressed as a rate per kilometer along the north-south volcanic arc, the result is 3 km^3/700,000 yr/km, or 11.6 m^3/day/km. The rate is very similar to the rate of 3 to 6 km^3/m.y./km (8.3 to 16.7 m^3/day/km) calculated for the Oregon Cascade Range from Crater Lake to the Three Sisters (Sherrod and Smith, 1989). From Three Sisters north to Mount Jefferson, the production rate has been estimated to be about the same 3 to 6 km^3/m.y./km (Sherrod, 1986).

Quaternary volcanic rock production along the southern Cascade Range of Washington

In Figure 4, the Quaternary volcanic rock volumes and production rates are portrayed per "segment" of the north-south oriented volcanic arc. The segments represent areas of different types of volcanism or relative absence of quaternary volcanic rock units, based on the geology from the state geologic map (Walsh and others, 1987). Volumes are from Smith (1989) and this study. The production rates are shown as total volcanic rock product volume of the past m.y. (most is for past 700,000 years), per km of length along the volcanic arc. Temperature gradient and heat flow values and approximate averages are also plotted along the length of the volcanic arc in Figure 5.

This portrayal demonstrates a very irregular pattern of volcanic production, with lowest activity north of Mount Rainier and south of Indian Heaven, (0 to 0.10 km^3/km). The rate increases several fold for the Goat Rocks, north of Mount Adams, and the Tumac Mountain segments (0.50, and 1.9 km^3/km). It jumps to 3.2 km^3/km at Indian Heaven, and reaches a maximum at the Mount Rainier and the Mount Adams/Mount St. Helens segments, (11.3 and 11.4 km^3/km respectively).

Even though the volcanic activity has been inconsistent along the volcanic arc, the same may not be true of total intrusive activity. The relatively consistent distribution of high temperature gradients and heat flow along the volcanic arc (Cascade heat flow anomaly described by Barnett and Korosec (1989), Korosec and Barnett (1989), and Blackwell and others, (1989, in progress), suggests that magmatic related heat production, and by inference, intrusive activity, should be similar throughout the southern Cascades of Washington. The only exceptions to this would be the segment north of Mount Rainier and the Columbia River to Mount Hood segment, where lower heat flow and low extrusive activity strongly suggests relatively lower and more restrictive intrusive activity.

CONCLUSIONS

Even though the results of age dating were disappointing, the author is willing to conclude from these studies that the Indian Heaven volcanic filed is younger than previously published data indicated, with all of the known flows exposed at the surface erupting over the past 730,000 years. The average production rate appears to have remained relatively constant over that interval, at a level not too different than the more silicic stratovolcanoes, and at a significantly greater rate than the other volcanic fields of primarily mafic flows.

The volcanic production expressed as a rate per length of volcanic arc is similar to rates estimated for much of the Oregon Cascade Range. When the entire southern Cascade Range of Washington is compared, a pattern of inconsistent volcanic production along the volcanic arc is quite apparent.

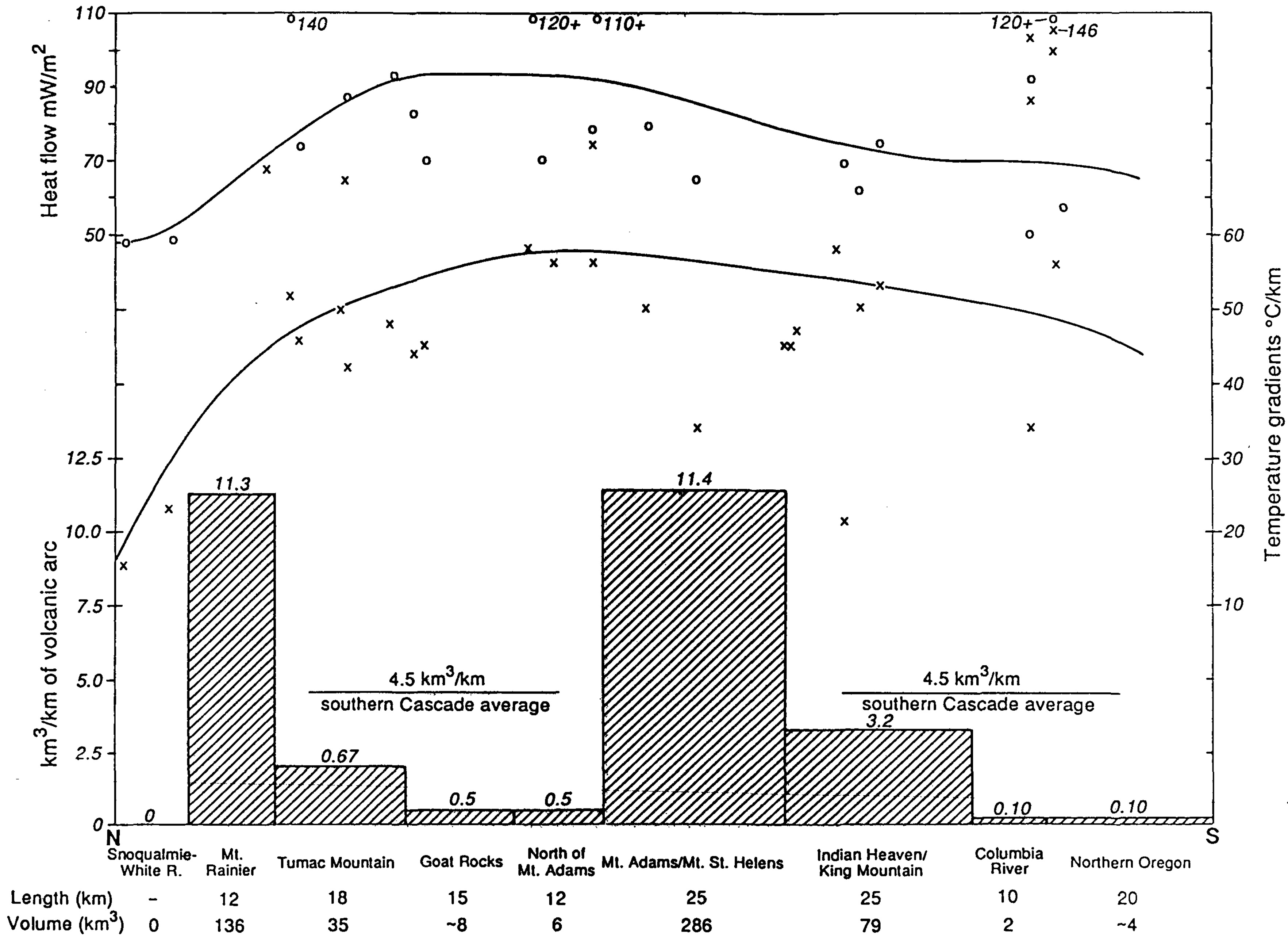


Figure 4. Volume and production rates of Quaternary volcanic rocks along the Cascade volcanic arc southern Washington. Only rocks less than 1 m.y. old are included. Temperature gradient (x) and heat flow (o) values along the arc are also plotted, along with average temperature gradient and heat flow trend lines.

The question which remains is how this pattern of volcanic production relates to intrusive activity. The pattern of relatively constant (and relatively high) temperature gradients and heat flow along the Cascade heat flow anomaly (Barnett and Korosec, 1989; Korosec and Barnett, 1989) would suggest relatively equal intrusive activity in the middle to upper crust. Lower heat flow values north of Mount Rainier and between the Columbia River and Mount Hood (Blackwell and others, 1989, in progress) and the observed low quaternary volcanic rock production suggest that intrusive activity along these sections of the arc are indeed lower than the intrusive activity for the rest of the arc.

Site specific areas within the Columbia River segment contain many hot springs and have produced numerous high termperature gradients and hot flowing water wells, while the areas of Mount Rainier and Mount St. Helens have produced several relatively low temperature gradients. This suggests that volcanic activity alone, disregarding structural control and style and composition of volcanic products, should not be used as an exclusive factor to target or exclude sites for geothermal exploration.

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Appendix A. Geochemical analyses for Indian Heaven and other southern Cascade Quaternary volcanic flows, originally presented as Tables 1, 2, 3, 4, and 8 in Hammond and Korosec (1983).

Table 1

SAMPLE NUMBER	LATITUDE	LONGITUDE	VOLCANIC ZONE	MAP UNIT	UNIT DESCRIPTION
1	4610.53	12138.24	3	QSM	ANDESITE OF SWAMPY MEADOWS
2	4612.53	12137.82	3	QAA	ANDESITE OF MOUNT ADAMS
3	4613.04	12137.62	3	QAA	ANDESITE OF MOUNT ADAMS
4	4618.58	12132.58	3	QSC	BASALT OF SPRING CREEK
5	4623.18	12131.97	3	QTLS	BASALT OF TWO LAKES
6	4625.31	12128.82	3	QWL	BASALT OF WALUPT LAKE
7	4604.01	12156.31	2	QTL	BASALT OF THOMAS LAKE
8	4604.18	12156.79	2	QTL	BASALT OF THOMAS LAKE
9	4603.75	12158.03	2	QLC	BASALT OF LAKE COMCOMLY
10	4604.22	12158.40	2	QTL	BASALT OF THOMAS LAKE
11	4604.77	12154.47	2	QIH	BASALT OF INDIAN HEAVEN
12	4605.11	12154.77	2	QTL	BASALT OF THOMAS LAKE
13	4603.15	12150.78	2	QLB	BASALT OF LONE BUTTE
14	4606.14	12147.83	2	QSL	BASALT OF SURPRISE LAKE
15	4605.80	12145.74	2	QSL	BASALT OF SURPRISE LAKE
16	4608.61	12146.35	2	QTC	BASALT OF TILLICUM CREEK
17	4553.61	12150.04	2	QBC	ANDESITE OF BLACK CREEK
18	4558.47	12143.29	2	QLC	BASALT OF LAKE COMCOMLY
19	4556.93	12143.17	2	QDC	BASALT OF DRY CREEK
20	4555.74	12146.05	2	QPM	BASALT OF PAPOOSE MOUNTAIN
21	4553.86	12149.49	2	QBC	BASALT OF BLACK CREEK
22	4554.03	12149.95	2	QBC	ANDESITE OF BLACK CREEK
23	4551.90	12149.55	2	QBC	ANDESITE OF BLACK CREEK
24	4601.28	12131.91	3	QGCY	BASALT OF GREEN CANYON
25	4602.98	12133.32	3	QGCY	BASALT OF GREEN CANYON
26	4606.82	12141.31	3	QWSC	BASALT WEST OF SKULL CREEK
27	4604.69	12139.59	3	QWSP	BASALT WEST OF SLEEPING BEAUTY
28	4604.09	12138.98	3	QWSC	BASALT WEST OF SKULL CREEK
29	4603.49	12136.70	3	QDH	BASALT OF DEADHORSE CREEK
30	4605.45	12141.80	2	QTLC	BASALT OF TROUT LAKE CREEK
31	4603.41	12137.75	3	QB	BASALT, UNDIVIDED
32	4601.02	12131.54	3	QCPK	BASALT OF COUNTY PARK
33	4603.03	12130.49	3	QSMB	ANDESITE OF SMITH BUTTE
34	4558.25	12125.00	3	QQB	ANDESITE OF QUIGLEY BUTTE
35	4558.04	12124.09	3	QQB	ANDESITE OF QUIGLEY BUTTE
36	4559.06	12121.34	3	QCP	BASALT OF CAMAS PRAIRIE
37	4559.06	12203.48	1	QSDP	BASALT OF SODA PEAK
38	4552.50	12205.30	1	QWC	ANDESITE OF WEST CRATER
39	4554.72	12205.61	1	QPC	BASALT OF PUNY CREEK
40	4554.97	12203.78	1	QBRM	BASALT OF BARE MOUNTAIN
41	4554.89	12141.52	2	QLC	BASALT OF LAKE COMCOMLY
42	4548.24	12141.52	2	QBL	BASALT OF BIG LAVA BED
43	4547.13	12137.80	2	QBL	BASALT OF BIG LAVA BED
44	4556.85	12138.66	3	QIH	RHYOLITE OF HANN BUTTE
45	4556.63	12135.73	2	QLC	BASALT OF LAKE COMCOMLY
46	4606.99	12207.62	1	QMMB	BASALT OF MARBLE MOUNTAIN
47	4552.76	12131.10	2	QIC	BASALT OF ICE CAVE
48	4554.55	12130.15	3	QGM	BASALT OF GULER MOUNTAIN
49	4551.73	12129.57	3	QGC	BASALT OF GILMER CREEK
50	4551.48	12129.82	3	QGC	BASALT OF GILMER CREEK
51	4551.26	12130.00	3	QGC	BASALT OF GILMER CREEK
52	4548.54	12128.05	3	QRS	ANDESITE OF RATTLESNAKE CREEK
53	4545.12	12130.73	3	QNW	BASALT OF NORTHWESTERN LAKE
54	4550.11	12123.48	3	QTDS	DACITE OF SNOWDEN
55	4544.49	12128.84	5	QMF	ANDESITE OF MCCOY FLAT

Table 1 (contd.)

SAMPLE NUMBER	LATITUDE	LONGITUDE	VOLCANIC ZONE	MAP UNIT	UNIT DESCRIPTION
56	4543.13	12128.84	5	QWS	BASALT OF WHITE SALMON
57	4543.13	12129.15	5	QWS	BASALT OF WHITE SALMON
58	4543.89	12130.58	5	QWS	BASALT OF WHITE SALMON
59	4544.62	12131.52	5	QUW	BASALT OF UNDERWOOD MOUNTAIN
60	4544.45	12132.99	5	QUW	BASALT OF UNDERWOOD MOUNTAIN
61	4543.72	12136.34	5	QUW	BASALT OF UNDERWOOD MOUNTAIN
62	4540.61	12156.19	4	QCLS	BASALT OF CASCADE LANDSLIDE
63	4537.84	12201.05	4	QBR	BASALT OF BEACON ROCK
64	4538.22	12201.23	4	QBR	BASALT OF BEACON ROCK
65	4537.59	12208.24	4	QMCC	BASALT OF MCCLOSKEY CREEK
66	4537.67	12213.65	4	QBPR	BASALT OF BEAR PRAIRIE
67	4533.95	12214.02	4	QMP	BASALT OF MT. PLEASANT
68	4535.08	12228.72	4	QPRH	BASALT OF PRUNE HILL
69	4536.95	12217.95	4	QMN	BASALT OF MT. NORMAY
70	4538.01	12212.79	4	QBM	BASALT OF BOBS MOUNTAIN
71	4534.27	12228.72	4	QMZ	ANDESITE OF MT. ZION
72	4604.35	12208.85	1	QMMA	ANDESITE OF MARBLE MOUNTAIN
73	4551.31	12202.15	1	QWC	ANDESITE OF WEST CRATER
74	4604.43	12208.48	1	QMMB	BASALT OF MARBLE MOUNTAIN
75	4555.31	12146.72	2	QPB	BASALT OF PAPOOSE MOUNTAIN
76	4559.62	12144.51	2	QLC	BASALT OF LAKE COMCOMLY
77	4600.17	12144.08	2	QLC	BASALT OF LAKE COMCOMLY
78	4607.07	12146.11	2	QTB	BASALT OF TWIN BUTTES
79	4609.46	12144.02	2	QWSB	BASALT OF WEST STEAMBOAT MOUNTAIN
80	4608.95	12146.17	2	QWSB	BASALT OF WEST STEAMBOAT MOUNTAIN
81	4603.41	12141.56	2	QLG	BASALT OF LITTLE GOOSE CREEK
82	4603.32	12144.88	2	QIVP	BASALT OF INDIAN VIEWPOINT
83	4603.28	12140.20	2	QIC	BASALT OF ICE CAVE
84	4619.60	12129.38	3	QSC	BASALT OF SPRING CREEK
85	4621.82	12132.71	3	QPH	BASALT OF POTATO HILL
86	4548.15	12141.65	2	QLVC	BASALT OF LAVA CREEK
87	4600.43	12126.13	3	QCP	BASALT OF CAMAS PRAIRIE
88	4605.58	12115.61	3	QCP	BASALT OF CAMAS PRAIRIE
89	4613.30	12159.88	1	QPF	BASALT OF PARADISE FALLS
90	4635.20	12137.44	2	QTSM	DACITE OF SNYDER MOUNTAIN
91	4601.28	12136.58	3	QFM	BASALT OF FLATTOP MOUNTAIN
92	4620.41	12144.51	2	QSRP	BASALT OF SUNRISE PEAK
93	4621.52	12143.52	2	QSC	BASALT OF SPRING CREEK
94	4620.88	12142.60	2	QECC	BASALT OF EAST CANYON CREEK
95	4547.22	12142.66	3	QLOC	BASALT OF LOST CREEK
96	4601.53	12145.37	2	QHL	BASALT OF HIDDEN LAKE
97	4600.26	12149.36	2	QEL	ANDESITE OF EUNICE LAKE
98	4605.11	12147.46	2	QRL	BASALT OF RED LAKE
99	4547.34	12137.07	3	QLPC	BASALT OF LAPHAM CREEK
100	4603.45	12150.16	2	QLB	BASALT OF LONE BUTTE
101	4547.56	12202.80	1	QMB	BASALT OF MOWICH BUTTE
102	4552.67	12131.10	2	QIC	BASALT OF ICE CAVES
103	4608.01	12210.39	1	QSHI	BASALT OF MOUNT ST. HELENS

Table 2

UNNORMALIZED MAJOR AND MINOR OXIDE DATA

SAMPLE NUMBER	% SIO2	% AL2O3	% FE (TOTAL)	% TIO2	% MNO	% MGO	% CAO	% NA2O	% K2O	% P2O5	% H2O	% CO2	UNNORMALIZED TOTAL
1	58.80	16.30	6.60	1.34	0.11	3.20	6.00	4.00	1.85	0.30	1.51	.	100.010
2	60.80	17.20	5.20	1.20	0.08	1.80	5.10	4.60	2.70	0.34	0.66	.	99.680
3	60.80	16.80	5.20	1.16	0.08	1.80	5.00	4.44	2.60	0.35	1.07	.	99.300
4	49.20	16.70	10.00	1.48	0.18	7.60	9.90	3.12	0.40	0.15	0.91	.	99.640
5	53.50	16.80	8.60	1.24	0.15	6.15	8.85	3.40	0.80	0.11	0.18	.	99.780
6	50.60	16.80	9.00	1.52	0.17	7.00	9.90	3.16	0.80	0.23	0.78	.	99.960
7	48.90	17.00	9.80	1.30	0.18	8.10	9.85	2.96	0.30	0.11	0.66	.	99.160
8	47.05	16.78	10.01	1.23	0.17	8.79	11.02	2.91	0.33	0.10	0.08	.	98.470
9	50.60	17.30	9.00	1.22	0.17	6.95	9.65	3.20	0.55	0.16	0.89	.	99.690
10	48.00	17.40	9.80	1.26	0.18	7.95	9.90	3.12	0.25	0.12	0.36	0.180	98.520
11	50.40	17.00	9.80	1.14	0.17	7.75	9.60	3.00	0.50	0.13	0.18	.	99.670
12	50.40	16.70	9.60	1.50	0.18	7.10	9.60	3.28	0.50	0.17	0.73	0.030	99.790
13	52.60	16.30	7.60	1.40	0.14	7.40	8.30	3.52	1.10	0.32	1.32	.	100.000
14	52.00	15.70	8.40	1.32	0.14	7.35	8.45	3.52	1.40	0.38	0.99	.	99.650
15	51.60	16.55	8.80	1.23	0.16	7.50	9.00	3.16	0.90	0.27	0.19	.	99.360
16	46.50	16.32	11.48	1.67	0.20	8.79	11.03	3.00	0.24	0.10	1.03	.	100.360
17	57.40	17.00	6.20	1.03	0.11	5.30	6.50	3.84	1.00	0.20	1.04	.	99.620
18	50.40	17.20	9.80	1.11	0.18	7.70	9.35	3.04	0.50	0.14	0.84	.	100.260
19	50.20	16.70	9.40	1.20	0.17	7.85	9.20	3.20	0.55	0.17	1.16	.	99.800
20	51.60	17.40	8.80	1.20	0.17	6.65	9.55	3.12	0.65	0.18	0.60	.	99.920
21	52.90	16.80	8.20	1.43	0.14	6.40	7.65	3.72	0.95	0.34	0.82	.	99.350
22	56.70	16.72	6.65	0.98	0.11	5.24	6.98	4.13	1.16	0.36	0.71	.	99.740
23	54.90	16.30	6.60	1.12	0.12	6.35	7.40	3.84	1.25	0.33	0.65	.	98.860
24	57.60	17.30	6.60	1.18	0.12	4.70	6.00	3.80	1.00	0.28	1.64	.	100.220
25	51.80	16.40	7.60	1.60	0.14	7.70	8.10	3.68	1.05	0.39	0.65	.	99.110
26	51.35	15.30	8.00	1.61	0.15	9.00	9.15	3.28	1.30	0.40	0.78	0.050	100.370
27	54.65	15.75	6.65	1.27	0.10	6.03	7.97	3.76	2.07	0.48	0.25	0.050.	99.030
28	50.80	16.70	9.00	1.33	0.16	7.45	8.90	3.04	0.70	0.21	1.37	0.080	99.740
29	52.80	16.20	9.20	1.64	0.16	5.80	7.95	3.40	1.10	0.29	0.45	.	98.990
30	50.40	17.60	9.00	1.16	0.17	7.50	9.60	3.08	0.40	0.27	0.85	.	100.030
31	54.20	17.00	6.80	1.23	0.13	6.05	8.00	3.92	1.10	.	1.05	.	99.480
32	51.40	16.70	9.40	1.70	0.17	6.05	8.75	3.52	0.90	0.28	0.62	0.080	99.570
33	56.60	17.30	6.60	1.50	0.11	4.00	6.80	3.88	1.45	0.35	1.26	.	99.850
34	55.00	16.90	7.40	1.34	0.13	4.55	7.80	3.80	1.10	0.22	1.26	.	99.500
35	54.30	16.40	7.60	1.38	0.14	6.05	7.40	3.80	1.35	0.27	0.95	0.030	99.670
36	52.50	16.55	8.00	1.44	0.15	5.90	8.45	3.48	0.80	0.29	1.29	.	98.850
37	53.20	16.20	6.60	1.20	0.12	6.75	7.80	4.00	1.35	0.44	1.19	0.080	98.930
38	55.90	16.90	5.80	1.14	0.10	3.70	7.60	4.40	1.70	0.55	1.91	.	99.700
39	54.10	16.40	6.20	1.14	0.11	7.40	7.25	4.00	1.45	0.34	0.89	.	99.280
40	51.80	16.00	7.80	1.74	0.13	6.75	8.25	4.00	1.40	0.35	0.91	.	99.130
41	50.70	16.90	9.40	1.20	0.16	7.85	8.85	3.16	0.45	0.14	1.14	.	99.950
42	50.10	17.30	9.40	1.36	0.17	7.85	8.85	3.16	0.50	0.18	0.77	.	99.640
43	49.20	17.30	9.80	1.38	0.17	8.35	9.45	3.16	0.50	0.16	0.89	.	100.360
44	74.80	14.20	0.60	0.10	.	.	0.65	3.60	4.10	0.02	0.98	0.030	99.080
45	49.80	16.90	9.60	1.27	0.17	8.00	9.60	3.12	0.55	0.19	0.11	.	99.310
46	52.00	15.80	8.20	1.48	0.13	7.05	8.05	3.68	1.35	0.37	0.98	0.030	99.120
47	48.40	17.40	10.80	1.14	0.18	8.00	9.70	3.08	0.25	0.10	0.84	0.030	99.920
48	49.10	17.30	9.60	1.42	0.17	7.70	9.70	3.08	0.50	0.16	0.31	.	99.040
49	49.40	17.10	10.20	1.40	0.18	7.05	10.05	3.08	0.55	0.21	0.70	0.030	99.950
50	49.60	17.80	10.00	1.42	0.17	7.05	9.50	3.24	0.70	0.24	0.60	0.050	100.370
51	50.88	16.19	9.72	1.39	0.15	7.14	9.87	3.67	0.61	0.23	0.17	.	100.020
52	56.40	17.85	7.11	1.12	0.12	3.74	6.95	4.31	1.36	0.25	0.72	0.075	100.005
53	51.06	17.16	9.75	1.65	0.15	5.41	8.82	3.71	1.06	0.28	0.76	0.075	99.885

Table 2 (contd.)

UNNORMALIZED MAJOR AND MINOR OXIDE DATA

SAMPLE NUMBER	% SIO2	% AL2O3	% FE (TOTAL)	% TIO2	% MNO	% MGO	% CAO	% NA2O	% K2O	% P2O5	% H2O	% CO2	UNNORMALIZED TOTAL
54	62.89	19.82	4.48	0.56	0.07	0.57	3.84	3.92	0.60	0.14	3.04	0.025	99.955
55	57.40	17.52	6.76	1.06	0.11	3.62	7.17	4.44	1.24	0.25	0.41	.	99.980
56	50.57	17.13	10.19	1.22	0.15	6.98	10.60	3.11	0.42	0.19	.	.	100.560
57	51.51	16.83	9.11	1.22	0.15	7.05	9.64	3.20	0.44	0.20	0.35	0.100	99.800
58	48.80	15.80	10.85	1.39	0.13	7.58	10.03	2.88	0.51	0.18	0.57	0.025	98.745
59	48.92	16.90	9.97	1.06	0.14	7.87	10.34	3.26	0.65	0.20	0.17	0.050	99.530
60	52.46	17.08	8.98	1.25	0.12	5.45	9.52	3.35	0.71	0.20	0.55	0.025	99.695
61	51.54	16.45	9.16	1.16	0.13	6.29	10.05	3.07	0.57	0.19	0.85	0.100	99.560
62	53.82	17.00	7.36	1.06	0.11	5.75	8.78	3.63	0.86	0.19	.	0.075	98.635
63	54.52	17.43	7.38	1.16	0.09	4.74	8.50	4.19	0.88	0.25	0.68	0.050	99.870
64	51.70	17.00	8.04	1.22	0.12	6.79	9.55	3.63	0.89	0.25	0.31	0.025	99.525
65	52.63	17.33	7.62	1.12	0.11	6.79	7.24	3.60	0.90	0.25	1.95	.	99.540
66	51.00	17.21	8.65	1.55	0.13	6.72	8.78	3.94	1.04	0.29	1.04	0.025	100.375
67	53.80	17.70	7.77	1.19	0.11	5.43	8.25	3.99	1.08	0.31	0.43	.	100.060
68	53.20	16.56	8.02	1.22	0.11	6.28	7.94	4.56	1.02	0.28	0.21	.	99.400
69	52.55	17.04	8.20	1.49	0.13	5.96	8.22	4.01	1.01	0.30	0.78	0.025	99.715
70	53.65	16.53	7.88	1.25	0.11	6.66	8.78	3.44	0.70	0.23	0.92	.	100.150
71	55.11	17.33	6.82	1.06	0.10	5.70	7.39	4.22	1.02	0.24	0.78	.	99.770
72	58.41	17.07	6.29	1.02	0.08	3.86	6.65	4.23	1.52	0.27	0.39	.	99.790
73	55.60	18.64	6.60	0.99	0.10	3.52	7.06	4.90	0.83	0.27	0.39	.	98.900
74	52.15	15.51	9.07	1.35	0.13	7.57	8.39	3.55	1.15	0.33	0.55	.	99.750
75	50.00	18.01	9.46	1.29	0.16	7.28	9.29	3.11	0.60	0.23	0.63	.	100.060
76	48.71	16.97	10.24	1.06	0.15	8.05	10.11	3.39	0.50	0.18	0.43	.	99.790
77	50.02	16.80	9.03	1.12	0.15	8.31	9.56	3.08	0.65	0.19	0.57	.	99.480
78	50.26	16.62	9.77	1.39	0.15	7.38	9.80	3.13	0.80	0.23	0.51	.	100.040
79	49.00	15.95	9.96	1.49	0.15	7.81	10.52	3.01	1.40	0.35	0.41	.	100.050
80	49.07	16.26	9.63	1.62	0.14	7.24	10.37	3.36	1.05	0.33	0.80	.	99.870
81	50.00	16.01	9.08	1.72	0.13	8.21	9.42	3.76	1.15	0.31	0.23	0.050	100.070
82	52.40	16.16	6.88	1.02	0.10	7.45	8.35	3.91	1.85	0.35	0.26	0.025	98.755
83	48.34	17.75	10.06	1.09	0.15	7.67	10.16	3.36	0.25	0.17	0.40	.	99.400
84	47.65	16.35	10.27	1.39	0.16	7.86	10.43	3.20	0.30	0.18	0.49	.	98.280
85	53.75	15.95	8.19	1.32	0.13	6.19	7.98	3.88	1.40	0.24	0.29	0.025	99.345
86	47.54	17.66	10.03	1.16	0.16	8.22	10.36	2.66	0.25	0.16	1.46	.	99.660
87	51.46	16.29	8.87	1.35	0.13	6.77	9.05	3.85	0.70	0.23	1.22	.	99.920
88	48.69	16.77	10.76	1.55	0.17	6.83	10.48	3.26	0.65	0.25	0.59	.	100.000
89	49.34	16.84	9.19	1.19	0.16	8.24	9.89	3.42	0.45	0.20	0.15	.	99.070
90	65.24	15.59	4.37	0.66	0.07	1.88	4.01	4.28	2.80	0.15	0.81	.	99.860
91	50.00	15.56	9.40	1.95	0.15	8.29	8.59	3.46	1.20	0.34	1.19	.	100.130
92	48.95	17.02	8.34	1.25	0.14	8.15	9.68	3.45	1.30	0.34	0.44	.	99.060
93	47.83	16.41	11.08	1.65	0.18	7.22	10.35	3.51	0.30	0.19	0.33	.	99.050
94	49.45	15.76	8.26	1.35	0.13	8.56	9.40	3.76	1.40	0.35	0.42	0.050	98.890
95	53.61	17.20	7.64	1.35	0.13	6.18	7.53	4.14	1.20	0.29	0.83	.	100.100
96	52.64	17.72	7.93	1.16	0.13	5.59	8.87	3.91	0.80	0.19	1.07	.	100.010
97	57.06	18.34	7.10	1.19	0.11	5.14	7.09	.	1.00	0.25	1.29	.	98.570
98	56.00	16.41	9.05	1.42	0.13	8.15	8.59	3.42	1.70	0.33	1.30	0.025	106.525
99	51.51	18.57	8.47	1.32	0.13	6.75	7.57	3.71	0.35	0.28	1.59	.	100.250
100	51.10	16.69	8.31	1.39	0.13	7.78	8.73	3.58	1.05	0.26	0.75	.	99.770
101	53.80	16.90	7.33	1.12	0.11	6.86	7.56	4.22	1.50	0.28	0.73	0.025	100.435
102	48.89	16.41	8.17	1.42	0.12	9.56	10.58	3.45	0.25	0.27	0.54	0.050	99.710
103	51.00	17.11	9.47	1.68	0.14	5.42	8.81	3.79	0.90	0.26	1.05	.	99.630

Table 3

MAJOR AND MINOR OXIDE DATA NORMALIZED TO 100% ON VOLATILE-FREE BASIS

SAMPLE NUMBER	% SIO2	% AL2O3	% FE (TOTAL)	% TIO2	% MNO	% MGO	% CAO	% NA2O	% K2O	% P2O5
1	59.70	16.55	6.70	1.36	0.11	3.25	6.09	4.06	1.88	0.30
2	61.40	17.37	5.25	1.21	0.08	1.82	5.15	4.65	2.73	0.34
3	61.90	17.10	5.29	1.18	0.08	1.83	5.09	4.52	2.65	0.36
4	49.83	16.91	10.13	1.50	0.18	7.70	10.03	3.16	0.41	0.15
5	53.71	16.87	8.63	1.24	0.15	6.17	8.89	3.41	0.80	0.11
6	51.02	16.94	9.07	1.53	0.17	7.06	9.98	3.19	0.81	0.23
7	49.64	17.26	9.95	1.32	0.18	8.22	10.00	3.01	0.30	0.11
8	47.62	17.05	10.17	1.25	0.17	8.93	11.20	2.96	0.34	0.10
9	51.21	17.51	9.11	1.23	0.17	7.03	9.77	3.24	0.56	0.16
10	48.99	17.76	10.00	1.29	0.18	8.11	10.10	3.18	0.26	0.12
11	50.66	17.09	9.85	1.15	0.17	7.79	9.65	3.02	0.50	0.13
12	50.89	16.86	9.69	1.51	0.18	7.17	9.69	3.31	0.50	0.17
13	53.30	16.52	7.70	1.42	0.14	7.50	8.41	3.57	1.11	0.32
14	52.71	15.91	8.51	1.34	0.14	7.45	8.56	3.57	1.42	0.39
15	52.03	16.69	8.87	1.24	0.16	7.56	9.08	3.19	0.91	0.27
16	46.81	16.43	11.56	1.68	0.20	8.85	11.10	3.02	0.24	0.10
17	58.23	17.24	6.29	1.04	0.11	5.38	6.59	3.90	1.01	0.20
18	50.69	17.30	9.86	1.12	0.18	7.74	9.40	3.06	0.50	0.14
19	50.89	16.93	9.53	1.22	0.17	7.96	9.33	3.24	0.56	0.17
20	51.95	17.52	8.86	1.21	0.17	6.70	9.62	3.14	0.65	0.18
21	53.69	17.05	8.32	1.45	0.14	6.50	7.76	3.78	0.96	0.35
22	57.26	16.88	6.72	0.99	0.11	5.29	7.05	4.17	1.17	0.36
23	55.90	16.60	6.72	1.14	0.12	6.47	7.53	3.91	1.27	0.34
24	58.43	17.55	6.70	1.20	0.12	4.77	6.09	3.85	1.01	0.28
25	52.61	16.66	7.72	1.63	0.14	7.82	8.23	3.74	1.07	0.40
26	51.59	15.37	8.04	1.62	0.15	9.04	9.19	3.30	1.31	0.40
27	55.35	15.95	6.74	1.29	0.10	6.11	8.07	3.81	2.10	0.49
28	51.68	16.99	9.16	1.35	0.16	7.58	9.05	3.09	0.71	0.21
29	53.58	16.44	9.34	1.66	0.16	5.89	8.07	3.45	1.12	0.29
30	50.82	17.75	9.07	1.17	0.17	7.56	9.68	3.11	0.40	0.27
31	55.06	17.27	6.91	1.25	0.13	6.15	8.13	3.98	1.12	.
32	51.99	16.89	9.51	1.72	0.17	6.12	8.85	3.56	0.91	0.28
33	57.41	17.55	6.69	1.52	0.11	4.06	6.90	3.94	1.47	0.36
34	55.99	17.20	7.53	1.36	0.13	4.63	7.94	3.87	1.12	0.22
35	55.02	16.62	7.70	1.40	0.14	6.13	7.50	3.85	1.37	0.27
36	53.81	16.96	8.20	1.48	0.15	6.05	8.66	3.57	0.82	0.30
37	54.47	16.59	6.76	1.23	0.12	6.91	7.99	4.10	1.38	0.45
38	57.16	17.28	5.93	1.17	0.10	3.78	7.77	4.50	1.74	0.56
39	54.99	16.67	6.30	1.16	0.11	7.52	7.37	4.07	1.47	0.35
40	52.74	16.29	7.94	1.77	0.13	6.87	8.40	4.07	1.43	0.36
41	51.31	17.10	9.51	1.21	0.16	7.94	8.96	3.20	0.46	0.14
42	50.67	17.50	9.51	1.38	0.17	7.94	8.95	3.20	0.51	0.18
43	49.46	17.39	9.85	1.39	0.17	8.39	9.50	3.18	0.50	0.16
44	76.27	14.48	0.61	0.10	.	.	0.66	3.67	4.18	0.02
45	50.20	17.04	9.68	1.28	0.17	8.06	9.68	3.15	0.55	0.19
46	53.00	16.10	8.36	1.51	0.13	7.19	8.21	3.75	1.38	0.38
47	48.86	17.57	10.90	1.15	0.18	8.08	9.79	3.11	0.25	0.10
48	49.73	17.52	9.72	1.44	0.17	7.80	9.82	3.12	0.51	0.16
49	49.79	17.23	10.28	1.41	0.18	7.11	10.13	3.10	0.55	0.21
50	49.74	17.85	10.03	1.42	0.17	7.07	9.53	3.25	0.70	0.24
51	50.96	16.21	9.73	1.39	0.15	7.15	9.88	3.68	0.61	0.23
52	56.85	17.99	7.17	1.13	0.12	3.77	7.01	4.34	1.37	0.25
53	51.55	17.32	9.84	1.67	0.15	5.46	8.90	3.75	1.07	0.28

Table 3 (contd.)

MAJOR AND MINOR OXIDE DATA NORMALIZED TO 100% ON VOLATILE-FREE BASIS

SAMPLE NUMBER	% SIO2	% AL2O3	% FE (TOTAL)	% TIO2	% MNO	% MGO	% CAO	% NA2O	% K2O	% P2O5
54	64.91	20.46	4.62	0.58	0.07	0.59	3.96	4.05	0.62	0.14
55	57.65	17.60	6.79	1.06	0.11	3.64	7.20	4.46	1.25	0.25
56	50.29	17.03	10.13	1.21	0.15	6.94	10.54	3.09	0.42	0.19
57	51.85	16.94	9.17	1.23	0.15	7.10	9.70	3.22	0.44	0.20
58	49.72	16.10	11.05	1.42	0.13	7.72	10.22	2.93	0.52	0.18
59	49.26	17.02	10.04	1.07	0.14	7.92	10.41	3.28	0.65	0.20
60	52.93	17.23	9.06	1.26	0.12	5.50	9.60	3.38	0.72	0.20
61	52.27	16.68	9.29	1.18	0.13	6.38	10.19	3.11	0.58	0.19
62	54.61	17.25	7.47	1.08	0.11	5.83	8.91	3.68	0.87	0.19
63	54.99	17.58	7.44	1.17	0.09	4.78	8.57	4.23	0.89	0.25
64	52.12	17.14	8.11	1.23	0.12	6.85	9.63	3.66	0.90	0.25
65	53.93	17.76	7.81	1.15	0.11	6.96	7.42	3.69	0.92	0.26
66	51.35	17.33	8.71	1.56	0.13	6.77	8.84	3.97	1.05	0.29
67	54.00	17.77	7.80	1.19	0.11	5.45	8.28	4.00	1.08	0.31
68	53.63	16.70	8.09	1.23	0.11	6.33	8.00	4.60	1.03	0.28
69	53.13	17.23	8.29	1.51	0.13	6.03	8.31	4.05	1.02	0.30
70	54.07	16.66	7.94	1.26	0.11	6.71	8.85	3.47	0.71	0.23
71	55.67	17.51	6.89	1.07	0.10	5.76	7.47	4.26	1.03	0.24
72	58.76	17.17	6.33	1.03	0.08	3.88	6.69	4.26	1.53	0.27
73	56.44	18.92	6.70	1.00	0.10	3.57	7.17	4.97	0.84	0.27
74	52.57	15.64	9.14	1.36	0.13	7.63	8.46	3.58	1.16	0.33
75	50.29	18.11	9.51	1.30	0.16	7.32	9.34	3.13	0.60	0.23
76	49.02	17.08	10.31	1.07	0.15	8.10	10.18	3.41	0.50	0.18
77	50.57	16.99	9.13	1.13	0.15	8.40	9.67	3.11	0.66	0.19
78	50.50	16.70	9.82	1.40	0.15	7.41	9.85	3.14	0.80	0.23
79	49.18	16.01	10.00	1.50	0.15	7.84	10.56	3.02	1.41	0.35
80	49.53	16.41	9.72	1.64	0.14	7.31	10.47	3.39	1.06	0.33
81	50.11	16.04	9.10	1.72	0.13	8.23	9.44	3.77	1.15	0.31
82	53.21	16.41	6.99	1.04	0.10	7.57	8.48	3.97	1.88	0.36
83	48.83	17.93	10.16	1.10	0.15	7.75	10.26	3.39	0.25	0.17
84	48.73	16.72	10.50	1.42	0.16	8.04	10.67	3.27	0.31	0.18
85	54.28	16.11	8.27	1.33	0.13	6.25	8.06	3.92	1.41	0.24
86	48.41	17.98	10.21	1.18	0.16	8.37	10.55	2.71	0.25	0.16
87	52.14	16.50	8.99	1.37	0.13	6.86	9.17	3.90	0.71	0.23
88	48.98	16.87	10.82	1.56	0.17	6.87	10.54	3.28	0.65	0.25
89	49.88	17.02	9.29	1.20	0.16	8.33	10.00	3.46	0.45	0.20
90	65.87	15.74	4.41	0.67	0.07	1.90	4.05	4.32	2.83	0.15
91	50.54	15.73	9.50	1.97	0.15	8.38	8.68	3.50	1.21	0.34
92	49.63	17.26	8.46	1.27	0.14	8.26	9.82	3.50	1.32	0.34
93	48.45	16.62	11.22	1.67	0.18	7.31	10.48	3.56	0.30	0.19
94	50.24	16.01	8.39	1.37	0.13	8.70	9.55	3.82	1.42	0.36
95	54.00	17.33	7.70	1.36	0.13	6.23	7.59	4.17	1.21	0.29
96	53.20	17.91	8.01	1.17	0.13	5.65	8.97	3.95	0.81	0.19
97	58.66	18.85	7.30	1.22	0.11	5.28	7.29	.	1.03	0.26
98	53.23	15.60	8.60	1.35	0.12	7.75	8.17	3.25	1.62	0.31
99	52.21	18.82	8.59	1.34	0.13	6.84	7.67	3.76	0.35	0.28
100	51.61	16.86	8.39	1.40	0.13	7.86	8.82	3.62	1.06	0.26
101	53.97	16.95	7.35	1.12	0.11	6.88	7.58	4.23	1.50	0.28
102	49.32	16.56	8.24	1.43	0.12	9.64	10.67	3.48	0.25	0.27
103	51.73	17.36	9.61	1.70	0.14	5.50	8.94	3.84	0.91	0.26

Table 4

TRACE ELEMENT CONCENTRATIONS (PPM)

SAMPLE NUMBER	LI	RB	CU	SR	BA	ZN	SC	Y	LA	CE	V	CR	NI
1	20	55	55	380	370	88	16	31	27	55	137	90	19
2	20	75	41	380	420	80	13	.	34	70	87	40	9
3	27	75	38	370	420	76	13	42	36	72	85	45	.
4	10	10	87	300	80	89	32	29	7	26	201	335	97
5	15	25	52	300	130	80	29	28	9	26	170	260	40
6	11	15	71	460	220	82	33	31	16	42	197	265	52
7	9	10	69	345	70	87	31	25	5	22	183	320	82
8	9	15	73	340	100	83	32	23	7	24	240	246	167
9	10	15	63	325	160	86	32	29	10	30	190	245	40
10	9	10	74	330	50	88	31	25	5	21	197	350	4
11	9	15	61	335	100	90	28	22	8	26	172	330	82
12	8	10	80	380	90	89	31	29	8	25	227	275	59
13	12	25	63	565	250	84	22	22	17	36	169	360	100
14	11	20	70	840	430	97	21	21	29	60	160	320	120
15	11	15	63	740	320	89	26	24	19	43	174	360	90
16	9	10	98	287	84	89	34	30	8	25	273	225	168
17	13	15	32	660	320	89	16	19	18	36	124	225	73
18	10	10	60	400	120	88	30	25	9	26	176	325	62
19	10	15	60	380	130	89	30	26	10	27	172	365	86
20	10	10	54	385	190	82	33	28	13	32	192	255	34
21	13	15	60	540	280	99	21	24	18	39	158	230	69
22	16	20	72	958	366	94	15	19	25	53	128	197	130
23	14	15	63	990	380	90	17	20	24	50	145	310	108
24	14	20	46	550	270	90	17	22	19	39	142	205	56
25	17	15	63	630	260	93	23	25	20	45	175	400	120
26	12	20	76	1020	430	90	23	21	26	59	193	565	178
27	47	25	75	1246	407	151	17	20	37	87	151	160	142
28	11	10	68	470	180	93	28	26	12	33	182	375	69
29	17	25	71	360	220	99	24	31	18	42	190	230	44
30	10	10	60	345	120	81	31	26	8	24	182	195	42
31	16	15	63	930	370	92	20	22	24	50	167	245	76
32	15	25	80	360	180	97	27	33	16	38	202	185	46
33	13	35	65	510	390	90	18	27	26	52	161	60	23
34	18	25	52	450	250	91	24	28	17	38	167	100	20
35	17	30	73	450	260	88	22	28	20	45	163	250	59
36	13	15	82	500	230	91	26	26	16	39	173	260	56
37	16	15	121	860	440	99	18	20	29	63	160	290	100
38	20	20	115	920	640	120	16	22	43	87	128	85	32
39	18	20	65	230	480	81	17	19	30	61	149	340	144
40	15	20	43	1030	370	100	19	22	28	63	183	310	79
41	87	15	78	300	120	174	27	26	6	28	182	365	76
42	12	10	68	360	130	75	28	24	8	28	198	365	76
43	10	10	65	370	120	73	27	24	8	28	198	380	79
44	7	150	5	60	690	38	3	34	32	67	11	30	11
45	11	15	63	315	130	74	28	26	24	28	183	355	59
46	12	15	90	750	360	89	20	23	25	57	167	315	83
47	9	10	77	265	70	88	26	23	5	21	176	290	79
48	.	10	.	350	270	.	.	.	.	.	.	375	76
49	9	10	63	320	160	81	32	28	10	31	203	245	28
50	11	10	70	405	200	81	28	28	14	38	198	285	51
51	10	17	60	365	190	82	26	26	12	39	185	173	102
52	14	20	51	576	372	82	15	25	21	47	122	74	58
53	14	26	73	376	252	85	23	31	18	44	185	144	88

Table 4 (contd.)

TRACE ELEMENT CONCENTRATIONS (PPM)

SAMPLE NUMBER	LI	RB	CU	SR	BA	ZN	SC	Y	LA	CE	V	CR	NI
54	18	7	33	409	524	75	8	20	34	51	56	23	21
55	13	30	47	563	376	81	15	25	21	47	121	69	59
56	9	16	65	381	127	78	27	24	7	27	190	184	107
57	9	12	84	509	178	82	25	21	11	34	184	214	125
58	11	14	65	408	124	93	26	23	10	37	173	169	122
59	9	19	60	429	233	78	25	21	15	43	165	192	147
60	17	18	42	484	199	149	26	24	14	44	179	111	54
61	12	12	53	439	168	82	26	22	13	42	83	138	70
62	11	12	47	560	217	73	17	16	11	31	143	155	115
63	14	16	53	644	234	89	19	18	17	44	140	78	75
64	9	16	60	751	368	74	19	20	17	45	165	173	130
65	14	16	43	608	245	86	20	19	19	43	158	148	158
66	14	18	65	622	209	89	22	24	17	46	186	213	122
67	13	18	59	856	413	89	19	20	25	60	155	119	102
68	14	16	51	709	356	89	19	22	20	49	150	159	145
69	13	15	54	641	241	89	22	35	26	50	186	154	119
70	12	11	53	772	309	87	18	18	17	46	150	179	143
71	14	16	43	849	372	88	17	18	19	44	146	112	140
72	14	21	37	851	283	80	14	19	24	54	131	68	56
73	18	16	53	677	240	92	14	20	15	38	122	66	58
74	15	21	76	604	268	107	22	24	20	51	175	178	172
75	13	13	53	376	199	92	34	30	14	43	210	152	77
76	13	12	55	392	138	88	31	26	10	31	189	175	124
77	10	16	52	410	169	74	27	24	11	32	164	216	132
78	9	16	65	504	251	81	26	25	15	42	201	203	107
79	14	30	68	718	478	99	31	31	30	73	227	239	97
80	13	17	68	621	274	90	29	28	23	57	220	158	87
81	13	21	68	611	245	88	24	25	21	49	190	234	166
82	16	30	45	946	500	92	20	20	37	81	170	242	164
83	11	9	70	287	72	86	24	21	6	24	161	166	116
84	12	12	80	254	73	86	30	27	8	33	198	281	140
85	17	30	55	397	233	84	21	27	22	54	157	171	101
86	10	10	65	244	71	73	32	25	7	29	175	152	127
87	12	13	63	476	191	84	24	24	17	44	169	189	96
88	12	16	63	338	165	96	32	30	12	41	206	179	73
89	13	11	88	336	111	81	30	25	9	29	203	211	145
90	22	81	28	318	475	62	11	25	32	59	86	36	26
91	15	23	65	618	286	103	22	25	24	56	195	215	176
92	13	24	79	756	368	79	32	27	28	67	180	203	146
93	13	10	98	256	86	93	35	31	8	30	233	171	117
94	14	23	71	888	396	82	26	24	33	73	170	246	175
95	13	16	59	624	256	78	19	25	20	44	159	150	124
96	13	18	60	464	194	73	24	23	13	36	179	97	53
97	17	21	52	594	283	87	16	20	17	42	133	106	97
98	12	28	62	955	532	92	22	23	38	82	156	193	177
99	14	10	54	637	262	96	18	25	23	47	147	148	144
100	14	21	56	506	258	81	20	22	18	46	163	221	156
101	15	24	52	774	445	85	18	20	30	67	145	171	150
102	14	10	54	779	395	83	17	20	25	57	147	105	96
103	15	22	84	405	240	90	26	32	15	44	201	132	73

Table 8. Alphabetical Key to Map Unit Symbols

Map Unit Symbol	Map Unit Name	Corresponding Samples
Qaa	Andesite of Mount Adams	2, 3, 141-152
Qb	Basalt west of Sleeping Beauty	27, 31, 161,162
Qbc	Andesite of Black Creek	17, 21, 22, 23, 121, 179
Qbl	Basalt of Big Lava Bed	42, 43, 116, 117, 118, 119
Qbm	Basalt of Vogel Creek	70
Qbp	Basalt of Burnt Peak	104, 105, 106
Qbpr	Basalt of Bear Prairie	66
Qbr	Basalt of Beacon Rock	63, 64
Qbrm	Basalt of Bare Mountain	40
Qby	Basalt of Berry Mountain	131, 194
Qcb	Cave Basalt	132, 133, 134, 135
Qcc	Basalt of Cedar Creek	130
Qchc	Andesite of Chinook Creek	165
Qcls	Basalt of Cascade Landslide	62
Qcp	Basalt of Camas Prairie	36, 87, 88
Qcpk	Basalt of County Park	32
Qdc	Basalt of Dry Creek	19
Qdh	Basalt of Deadhorse Creek	29
Qecc	Basalt of East Canyon Creek	94
Qecr		186
Qel	Andesite of Eunice Lake	97
Qern	Basalt of Ecklandt Ridge, North	163
Qfl	Andesite of Forlorn Lakes	129, 154, 193
Qflu	Andesite of Forlorn Lakes	198
Qfm	Basalt of Flattop Mountain	91
Qgc	Basalt of Gilmer Creek	49, 50, 51
Qgcy	Basalt of Green Canyon	24, 25
Qgl	Basalt of Goose Lake	182
Qgm	Basalt of Guler Mountain	48
Qgp	Basalt of Gifford Peak	115
Qhl	Basalt of Hidden Lake	96, 159, 181
Qic	Basalt of Ice Cave	47, 83, 102
Qih	Basalt of Indian Heaven	11, 107, 108, 122, 128
Qim	Rhyolite of Mann Butte	44
Qivp	Basalt of Indian Viewpoint	82
Qjc	Andesite of Juice Creek	127, 153, 183
Qlb	Basalt of Lone Butte	13, 100
Qlc	Basalt of Lake Comcomly	9, 18, 41, 45, 76, 77,
	" " " "	114, 156, 196
Qlg	Basalt of Little Goose Creek	81, 158, 180
Qloc	Basalt of Lost Creek	95
Qlpc	Basalt of Lapham Creek	99
Qlvc	Basalt of Lava Creek	86
Qmb	Basalt of Mowich Butte	101
Qmc	Andesite of Meadow Creek	112, 157, 177
Qmcc	Basalt of McCloskey Creek	65
Qmf	Andesite of McCoy Flat	55
Qmma	Andesite of Marble Mountain	72
Qmmb	Basalt of Marble Mountain	46, 74, 136
Qmn	Basalt of Mt. Normay	69
Qmp	Basalt of Mt. Pleasant	67
Qmz	Andesite of Mt. Zion	71

Map Unit Symbol	Map Unit Name	Corresponding Samples
Qnbm	Basalt North of Bird Mountain	192
Qner	Andesite of NE Red Mountain	190
Qnw	Basalt of Northwestern Lake	53
Qoc	Basalt of Outlaw Creek	113
Qpb	Basalt of Papoose Mountain	75
Qpc	Basalt of Puny Creek	39
Qpf	Basalt of Paradise Falls	89
Qph	Basalt of Potato Hill	85
Qpl	Basalt of Placid Lake	184
Qpm	Basalt of Papoose Mountain	20, 120, 188
Qprh	Basalt of Prune Hill	68
Qqb	Andesite of Quigley Butte	34, 35
Qrkb	Basalt of Rock Creek	125, 126
Qrl	Basalt of Red Lake	98
Qrp	Basalt of Ruthon Point	139, 140
Qrs	Andesite of Rattlesnake Creek	52
Qsbm	Basalt of SE Bird Mountain	185
Qsc	Basalt of Spring Creek	4, 84, 93
Qsdp	Basalt of Soda Peak	37
Qser	Basalt of SE Red Mountain	187
Qsh	Basalt of Mount St. Helens	103, 137, 138
Qsl	Basalt of Surprise Lake	14, 15, 110, 111, 164, 178
Qsm	Andesite of Swampy Meadows	1
Qsmb	Andesite of Smith Butte	33
Qspl	Basalt of Sheep Lakes	189, 195
Qspr	Basalt of Sunrise Peak	92
Qstm	Basalt of Sawtooth Mountain	191
Qtb	Basalt of Twin Buttes	78
Qtc	Basalt of Tillicum Creek	16
Qtch	Basalt of Trout Creek Hill	123, 124, 155
Qtds	Dacite of Snowden	54
Qtl	Basalt of Thomas Lake	7, 8, 10, 12, 109, 176
Qtlc	Basalt of Trout Lake Creek	30
Qtls	Basalt of Two Lakes	5
Qtp	Basalt of Timbered Peak	160
Qtsm	Dacite of Snyder Mountain	90
Qtw	Basalt of The Wart	197
Quw	Basalt of Underwood Mountain	59, 60, 61
Qwc	Andesite of West Crater	38, 73
Qwl	Basalt of Walupt Lake	6
Qws	Basalt of White Salmon	56, 57, 58
Qwsc	Basalt West of Skull Creek	26, 28
Qwsb	Basalt of Tillicum Creek	79, 80
Qwsp	Basalt West of Sleeping Beauty	27

Appendix B. Geochemical analyses for Indian Heaven flows, originally presented in Hammond (written communication, 1985).

Figure 5. SUMMARY OF CHEMISTRY OF INDIAN HEAVEN LAVA-FLOW UNITS (3 XI 84)

Unit #	Symbol	#Analyses	SiO2	Al2O3	FeO	MgO	CaO	Na2O	K2O	TiO2	MnO	P2O5	FeO+MgO	Mg'	K2O+Na2O	TiO2/P2O5
4	bbl	4	49.34	17.55	9.60	7.90	10.34	3.20	0.41	1.30	0.17	0.19	17.50	0.390	3.61	6.84
6	bbp	1	49.71	17.96	10.95	7.18	9.69	2.41	0.38	1.30	0.20	0.21	18.13	0.337	2.79	6.19
7	blb	2	52.46	16.69	8.05	7.68	8.62	3.60	1.09	1.41	0.14	0.29	15.73		4.69	4.86
8	bwsb	2	49.32	16.21	9.86	7.58	10.52	3.21	1.24	1.57	0.15	0.34	17.44	0.374	4.45	4.62
9	bst															
10	bih	2	50.20	17.90	9.80	7.59	9.78	2.69	0.46	1.22	0.18	0.20	17.39	0.375	3.15	6.10
11	bnst	1	53.23	15.60	8.60	7.75	8.17	3.25	1.62	1.35	0.12	0.31	16.35		4.87	4.35
12	blc	7	50.28	17.23	9.73	7.95	9.67	3.14	0.52	1.16	0.16	0.16	17.68		3.66	7.25
13	bspl	2	51.69	17.29	9.14	6.73	8.49	3.56	0.96	1.59	0.15	0.40	15.87		4.52	3.98
14	bic	2	48.85	17.75	10.53	7.92	10.03	3.25	0.25	1.13	0.17	0.14	18.45	0.437	3.50	8.07
15	bnbm	1	51.44	16.50	9.60	8.02	8.69	3.15	0.82	1.35	0.15	0.28	17.62		3.97	4.82
17	bivp	1	53.21	16.41	6.99	7.57	8.48	3.97	1.88	1.04	0.10	0.36	14.56	0.457	5.85	2.89
18	bgb															
19	afu	1	58.63	17.93	6.62	3.76	6.76	4.00	1.02	0.99	0.11	0.29	10.38	0.306	5.02	3.41
20	btw	1	53.81	17.84	7.64	6.88	7.79	3.63	0.79	1.22	0.12	0.29	14.52		4.42	4.21
21	bpb															
22	bsbm	1	52.30	15.92	7.40	8.23	8.84	3.41	2.06	1.20	0.12	0.52	15.63		5.47	2.31
23	bsrm															
24	bdh	1	53.58	16.44	9.34	5.87	8.07	3.45	1.12	1.66	0.16	0.29	15.23		4.57	5.72
25	anrm	1	58.43	17.67	6.57	4.22	6.85	3.93	1.00	0.95	0.10	0.28	10.79		4.93	3.39
26	bhl	2	52.57	17.71	8.33	6.42	8.63	3.79	0.85	1.33	0.14	0.25	14.75		4.64	5.32
27	bcnl	1	51.31	16.48	9.77	7.90	8.73	3.39	0.74	1.28	0.16	0.24	17.67		4.13	5.33
28	berm	4	50.37	17.95	9.35	7.05	10.13	2.97	0.54	1.27	0.17	0.20	16.40		3.51	6.35
30	blg	2	51.96	16.89	8.63	7.09	8.72	3.69	1.03	1.58	0.13	0.30	15.72		4.72	5.27
31	btb	1	50.50	16.70	9.82	7.41	9.85	3.14	0.80	1.40	0.15	0.23	17.23		3.94	6.09
32	btc	1	46.81	16.43	11.56	8.85	11.10	3.02	0.24	1.68	0.20	0.10	20.41		3.26	16.80
33	afl	2	57.92	17.92	6.63	4.28	7.04	3.94	0.93	0.98	0.11	0.27	10.91		4.87	3.63
34	bgl	1	50.33	16.07	8.64	9.28	9.25	3.23	1.23	1.44	0.14	0.38	17.92		4.46	3.79
35	bsl	5	51.37	16.54	9.15	7.65	9.13	3.14	1.20	1.32	0.15	0.35	16.80		4.34	3.77
36	btlc	2	49.59	17.87	9.64	7.97	10.12	2.91	0.33	1.18	0.17	0.22	17.61		3.24	5.36
37	bpl	1	49.10	15.86	10.36	8.47	9.08	3.00	1.38	2.12	0.16	0.47	18.83		4.38	4.51
38	amc	2	54.15	17.56	7.73	6.29	7.79	3.79	0.96	1.31	0.13	0.31	14.02		4.75	4.23
39	brc	1	50.52	17.02	9.82	8.03	8.82	3.38	0.70	1.31	0.16	0.24	17.85		4.08	5.46
40	bdc	1	50.89	16.93	9.53	7.96	9.33	3.24	0.56	1.22	0.17	0.17	17.49		3.80	7.18
41	ael	1	56.29	18.13	7.06	4.76	6.89	4.35	0.97	1.15	0.12	0.28	11.82		5.32	4.11
42	bgp															
43	bby	2	50.96	15.57	9.09	8.90	9.34	3.30	1.04	1.34	0.14	0.32	17.99		4.34	4.19
44	ajc	2	54.69	17.29	7.41	6.76	7.94	3.77	0.72	1.06	0.12	0.26	14.17		4.49	4.08
45	bwsc	2	51.61	16.18	8.60	8.31	9.12	3.20	1.01	1.50	0.16	0.31	16.91		4.21	4.84
46	bab															
47	abb															
48	bnsp															
49	abc	5	56.32	17.13	7.00	5.79	7.19	3.95	1.06	1.14	0.12	0.30	12.79		5.01	3.80
~~50~~	~~btl~~	5	49.19	17.22	10.12	8.11	10.31	3.06	0.33	1.34	0.18	0.13	18.23		3.39	10.31
51	boc	2	51.57	17.19	9.32	7.22	8.58	3.09	0.96	1.56	0.17	0.34	16.51		4.05	4.59
52	bmm	1	50.21	16.70	9.62	8.60	9.54	2.92	0.60	1.41	0.16	0.24	18.22		3.52	5.88