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STANFORD GEOTHERMAL PROGRAM
STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305

Soviet-American Monograph on Geothermal Energy

To: Patrick Muffler, Hugh Murphy, John Lund
All American Co-Authors

Subject: NewsMemo No. 9

Date: 16 December 1991

It looks like the long wait to begin the Monograph may finally be over! We have received the enclosed letters from Yuri Dyadkin (SPMI) which spell out the request to the Soviet authors to initiate contact. I hope my translations are close enough to the Russian original. What remains to be seen is whether the Soviet authors respond and whether we can handle the influx of correspondence in Russian.

We have also received the Telex advising us of the postponement of the International Symposium from 1992 to June, 1993. Since the Soviet Geothermal Association wants the Symposium built along the flow of the Monograph, it appears that the Chapters could be successfully prepared in the new time frame. I hope the long awaited response from the Soviet co-authors will begin by the first of 1992.

This may also give us time to get help on translations and perhaps funding for the trip in 1993. I still plan to put together a complete listing of Authors (both sides), addresses, and telephone and Fax numbers. So if you haven't yet responded to my request in the last Newsmemo please do so now.

Will look to hearing from you (as will your Volume Editor) as you correspond with your Co-author. In the meantime, let me take this opportunity to thank each of you for your patience and to wish you a Very Happy Holiday Season and New Year.

Paul Kruger

СОВЕТСКАЯ ГЕОТЕРМАЛЬНАЯ АССОЦИАЦИЯ

СССР 199026 ЛЕНИНГРАД

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XI. 1991.

To Authors and Editors of the Soviet-American Monograph
"GEOTHERMAL ENERGY"

Greetings:

As you know, on 10 October in Moscow (at the Geological Institute) took place a working meeting of the editors and authors of the Soviet-American Monograph with participation of the chief editor from the USA, Prof. P. Kruger (Stanford), which conveyed the well-founded dissatisfaction of the work of the Soviet colleagues: of the 26 American experts, who a year ago presented short Outlines of the contents of their chapters, only three received "responsive" suggestions from the Soviet co-authors (A.V. Kiryukhin, Yu.D. Dyadkin, S.G. Gendler - all from Vol.2). Transmitted to P. Kruger were prepared manuscripts of our parts of chapters 1.1, 1.2, 1.3, 1.4, 1.5, the American authors were not inclined to acknowledge sharing in the joint work, because they were written without agreement on the outlines and distribution between co-authors of the Sections of these chapters of Volume 1.

For Volume 3, for a year there was not even "appearance" of an Editor, although except for V.A. Vasiliev (ENIN) and V.N. Moskvichevoy no one of the participants of the Monograph declined...

In the letter of 30 October, P. Kruger advised that right after his trip to us there was discussion between the American Volume Editors.

P. Muffler (Vol.1) insisted on agreement on the Outlines and distribution by co-authors by chapter, noting, that only after this will it be possible to complete, revise, and finalize the manuscripts for Volume 1.

H. Murphy (Vol.2) dir not support the suggestion of E.I. Boguslavsky on changing the titles of the chapters and addition of other chapters to the volume, noting that it is premature and awaits Soviet Outlines (of seven) chapters for agreement.

J. Lund (Vol.3) was informed that B.M. Kozlov at the end of October was planning to be at SPMI for revision of the roster of authors; it awaits further objective information...

P. Kruger notes the general feelings of the American colleagues:

1) it is necessary to conclude the preliminary stage - agreement on detailed Outlines of the Chapters and distribution of Sections between the Co-authors. Only after this will it be possible to write the joint work and plan its completion.

2) not to change the accord of a year ago on the composition of the volumes, chapters, and their titles. After completion of the initial stage, writing, agreement between co-authors and submission of chapter manuscripts to the Volume Editors, their (editors) review: to evaluate the completeness of coverage of the scope, indicate revisions and "gaps" in coverage of the chapters and volumes, if necessary, - to suggest new Sections, Chapters, changes in titles and structure of the Monograph. Not earlier!

3) the International Symposium on the basis of the Monograph in June 1992 comes too soon. Without preliminary contact with Soviet co-authors, the American papers are not being prepared and in general they will not come (each must obtain funding of $3000, not so easy).

I am in agreement with these recommendations.

On receipt 14 Nov 91 of a Telex from Dr. J. Garnish (EEC, Vice-President, IGA) - a similar suggestion to postpone the Symposium to 1993. In early September 1992 there will be a broad geothermal conference in Iceland. The dates are too close and it appears that we will have too few foreign participants.

I expect that we will postpone the Symposium to 1993 (probably 21-27 June 1993).

But I very much request to send your co-author (if you have not yet) the Outline of the contents of your Chapter with indications which Sections you propose to write and finally to resolve controversial questions to your co-author, and how with that responsibilities and rights - by yourselves. In Russian to Co-authors, Volume Editors, and me. To Co-authors - by Express Mail, but better - by Fax.

And I advise not to be lacking: if by 1 Jan 92 I do not receive such a newyear present, it will signify that you prefer that I invite another expert.

Early wishes for the coming New Year !
I wish you success and everything good !

Sincerely,

Prof. Yu.D. Dyadkin
Editor of the Monograph
President SGA

СОВЕТСКАЯ ГЕОТЕРМАЛЬНАЯ АССОЦИАЦИЯ

СССР 199026 ЛЕНИНГРАД

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199004, Ленинград, Средний пр., 29

25.XI.91

25 November 1991

Dear Paul:

I send you and your family best wishes for Christmas and the coming New Year. I wish for a successful 1992 - a year of our working together on completing the joint Monograph and preparations for the International Symposium in 1993.

I received your Express-Mail packets of 31 October (to the Institute) and of 7 November (to home) at the same time on 14 November. More precisely, for the home address I received only a notification, and for the packet I went to the main post office only after a short trip to Moscow. Also on 14 November I received a Telex from J. Garnish. We decided to accept your recommendations and postpone the Symposium to 21-27 June 1993. On 18 November on this decision, we sent Telexes to you and Garnish (Litvinenko says that he sent them himself).

I see that you already started activities for announcing the Symposium. Now, I regret, it will be necessary to send out new information on the postponement schedule.

The draft chapter of H. Murphy for our Monograph was read with much interest. It appealed to me. For "history" it brought something new for me. I am very delighted.

On 21 November I received two letters from you (No.1 and No.3, as yet somewhere on the way is No.2...) with photographs (Santa Monica and our dacha) for which I thank you. They, as always, of high quality.

On the same day (about 18 November) a Fax arrived (from the Embassy in Moscow and the Consulate in St. Petersburg) from D. Duchane of Los Alamos * asking for my full name, in connection with the conference of 6-8 December. We concluded that this was for a ticket for British Airways as we had discussed. Prior, the invitation for this conference in Los Alamos I had not received.

On 18 November these data were sent by Fax to the Consulate, and on the 22nd also by Fax - to D. Duchane and copy to you. We agreed with L.A. Bliznets not to wait for the air ticket, to apply for a Visa, but it proved to be already too late: it is necessary to apply by 15 days and the flight had to be 1 December. Still at the Consulate was refused our diplomat. And I because of the prospective travel was not able to write you, "held back" this letter for a week...

We will assume that all this will not take place - for the best...

Now for us there is time for careful preparation of the Symposium and work on the Monograph.

Enclosed is the text of the letter which I am sending to all Soviet co-authors. For Volume 3 the situation remains difficult. I am seeking an active Editor. There will be progress - I will write.

Life for us is continually deteriorating. Now even for bread there are long lines. We for the present are not starving only thanks to the energy of Irene. We look forward to improvement.

All is well! Merry Christmas and Happy New Year!
Regards from Irene, Tatyana, the faculty and staff of the Laboratory.

With Best Wishes,

Yuri D. Dyadkin

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Soviet-American Monograph on Geothermal Energy

To: Patrick Muffler, Hugh Murphy, John Lund
All American Co-Authors

Subject: NewsMemo No. 4

Date: 30 November 1990

This will be the final NewsMemo of 1990 !
The Set of Proposed Outlines from the U.S. Co-Authors is now complete, and the final three (copies enclosed) are now on the way to LMI. The Set (less these three) were DHL-expressed to LMI on November 1.

During Prof. Dyadkin's visit, we noted that a few "Biggies" were going to Co-Author too many Chapters, so he agreed to revise the roster of Soviet Co-Authors on return. I have just received the revised list, and have amended those Outlines where the Soviet Co-Author has been changed. I have also revised Outlines where addresses or phone numbers have changed. If yours is one of these, a revised Outline is enclosed. One problem noted by Prof. Dyadkin was that there are no Faxes at most Soviet institutions and Telexes are generally used for rapid (one week) communications. Please take a moment and check your Outline for corrections to mailing address, telephone number, Fax number, and Telex number, where available. Please mail me any changes and I will keep a current edition of the data. I will send telex numbers (and any changes) to LMI as received.

There have been questions on what an "Annual Reviews"-type of coverage is. Enclosed is an Annual Reviews chapter on Geothermal Energy prepared 15 years ago (!) for Annual Reviews Vol 1 (1976). It has been very interesting to reconstruct the outline for this review (also enclosed) and compare it with our Monograph. We have come a long way since 1976, but a lot of the review would be pertinent if written today.

As I noted in the previous NewsMemo, the Ball is now in the Soviet Court. We should be receiving the first of the counter-proposed Outlines soon. As I also noted, I will assist anyone with trouble in translating responses in Russian. Please send me (and your Co-Editor) copies of the Soviet responses as they arrive so that we can keep tabs on progress towards the final Outlines and preparation of the first drafts by April, 1991.

In closing, let me wish each of you a very Happy Holiday Season !! I hope to see some of you at the Stanford Workshop in January.

~~With Best Wishes~~ for the New Year,
Paul Kruger

Topic Outline

Geothermal Energy
Annual Reviews of Energy, 1976

Chapter 1.4
EXPLORATION GEOSCIENCES

American CoAuthor: Phillip M. Wright — Tel: 801+524-3439
Univ. Utah Res. Inst. — Fax: 801+524-3453
391 Chipeta Way Suite.C — Tlx: tbd
Salt Lake City, UT 84108

Soviet CoAuthor: Vladimir I. Kononov — Tel: tbd
Geological Institute AS — Fax: tbd
Pihzevsky Per., No.7 — Telex: tbd
Moscow 109017 USSR

Chapter Outline
(21 Sep 90)

Suggested Responsible Co-Author

I. Introduction (PMW ?)
  A. Objective of Chapter
    To review application of geological, geochemical, and, geophysical techniques to regional exploration for geothermal resources
  B. History of geothermal exploratio
    Brief summary of early development, techniques used, philosophy
  C. Summary
    Summary of exploration methods and exploration strategies
II. Review of Regional Exploration Techniques
  A. Classification of techniques and comparison of techniques used to those used for mining and petroleum exploration
  B. Geological techniques of geologic mapping; study of drill samples; age dating; structural studies; geologic interpretation
  C. Geochemical techniques of chemistry of thermal fluids; major,minor, and trace elements in rocks; hydrothermal alteration; isotope studies; fluid inclusions
  D. Geophysical techniques of thermal, electrical, gravity, magnetic, seismic, and seismological methods, and remote sensing
III. Regional Exploration Strategies
  A. Summary of application of geosciences, exploration strategies
  B. Regional area selection with characteristics of geothermal environments (arid, wet, crystalline-rock, volcanic-rock, sedimentary-rock
  C. Regional exploration, exploration process, regional exploration strategies
IV. Exploration Case Studies (also for USSR ?)
  A. Geothermal provinces in the USA; summary of regional exploration in the USA
  B. Exploration of the Basin and Range, western USA
  C. Exploration of the Imperial Valley, southwest USA
V. Future Expectations and Research Needs
  A. Future of geothermal exploration in the USA (PMW?)
  B. (same for USSR ?) (VIK?)
  C. Research needed to improve exploration techniques
VI. Discussion and Conclusions

Chapter 1.2
HEAT FLOW DISTRIBUTION AND GEOTHERMAL ANOMALIES

American CoAuthor: David D. Blackwell — Tel: 214+692-2745
Geological Sciences Dept. — Fax: 214+692-4289
Southern Methodist Univ.
Dallas, TX 75275-0395

Soviet CoAuthor: Yakov B. Smirnov — Tel: tbd
Geological Institute AS — Fax: tbd
Pihzevsky Per., No.7 — Telex: tbd
Moscow 109017 USSR

Chapter Outline
(21 Nov 90)

Suggested Responsible Co-Author

I. Introduction (DDB ?)
- A. General controls on continental heat flow
- B. Tectonic and age divisions

II. Heat Flow in Stable Continental Regimes
- A. Cratons
- B. Platforms
- C. Basins

III. Heat Flow in Mobile Belts
- A. Subduction zones
- B. Continental collision zones
- C. Continental rifting and extension
- D. Transform faults
- E. Hot spots
- F. Others

IV. Geothermal Anomalies in Stable Continental Regimes
- A. Basement thermal anomalies
- B. Basin thermal anomalies

V. Geothermal Anomalies in Mobile Belts
- A. Subduction zones - volcanic arc settings
- B. Subduction zones - back arc settings
- C. Continental collision zones
- D. Continental rifting and extension
- E. Transform faults
- F. Hot spots
- G. Others

VI. Discussion

VII. References (as compiled)

Chapter 1.5
PROSPECT EVALUATION

American CoAuthor:	Norman E. Goldstein Earth Sciences Division Lawrence Berkeley Laboratory Berkeley, CA 94720	Tel: 415+486-5961 Fax: 602+527-7169 Tlx: tbd
Soviet CoAuthor:	Anna B. Vainblat Leningrad Mining Institute 21st Liniya No.2 Leningrad 199026 USSR	Tel: tbd Fax: tbd Telex: tbd

Chapter Outline
(29 Nov 90)

Suggested Responsible Co-Author

I. Introduction (NEG ?)
   A. Purpose of Chapter
   B. Early history of prospect evaluation
II. Methods of Prospect Evaluation
   A. Objectives
   B. Detailed surface studies
      Geology, geochemistry, geophysics
      Shallow temperature measurements
   C. Intermediate-depth drilling investigations
      Drilling, sampling, and logging
      Geologic analysis
      Flow testing
      Preliminary economic evaluation
III. Case Histories
   A. USA
   B. USSR
IV. Discussion
V. References (as compiled)

Chapter 2.3
WELL AND RESERVOIR TESTING

American CoAuthor: Mohinder S. Gulati — Tel: 707+545-7600
Unocal Geothermal Div. — Fax: 707+545-8746
3576 Unocal Place — Tlx: tbd
Santa Rosa, CA 95406

Soviet CoAuthor: Yuri M. Pariisky — Tel: tbd
Leningrad Mining Institute — Fax: tbd
21st Liniya No.2 — Telex: tbd
Leningrad 199026 USSR

Chapter Outline (14 Nov 90) — Suggested Responsible Co-Author

I. Introduction (MSG ?)
- A. Objectives
  1. Review traditional methods and tools used in well and reservoir testing in geothermal applications
  2. Offer comparisons with oil and gas tools and techniques where applicable
  3. Show how testing is utilized to render information needed for resource evaluation (deliverability and reserves estimates)
  4. Demonstrate the practical application of reservoir test results to prudent reservoir management
- B. Well Test History
  1. Early test methods, tools and analytical techniques
  2. Current test methods, tools, and analytical techniques
- C. Well Test and Reservoir Definitions
  1. Methods and techniques discussed here will be those in deep wells rather than shallow exploration wells. Itemizing of useful terms and definitions

II. General Characteristics
- A. Static Testing
  1. Temperature gradients
  2. Pressure gradients
  3. P-T survey series after flowing/injection
  4. Long-term monitoring
- B. Dynamic Testing
  1. Flowing well performance
  2. Injection well performance
  3. Flowmeter logging
  4. Wellbore simulation
  5. Tracer testing

C. Transient Testing
   1. Appropriateness of pressure transient analysis
   2. Types of transient tests
      a. pressure buildup
      b. pressure falloff
      c. drawdown
      d. multi rate
      e. interference
   3. Determination of fundamental reservoir properties: kh, Φh, skin, volume

D. Geochemistry

III. Summary of Past Experience

Review the items under general characteristics and describe which of these tools/techniques were available or in use 15-20 years ago

IV. Current Status of Development

Review the current practice of static, dynamic, and transient testing techniques and tools

V. Future Expectations and Research Needs

A. Improvements in downhole tool design

B. Improvements in data logging equipment

C. Analysis

VI. Conclusions

VII. References (as compiled)

Society of Exploration Geophysicists

December 13, 1991

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Salt Lake City, UT 84108

SEG/MOSCOW '92 INTERNATIONAL CONFERENCE & EXPOSITION

Dear Colleague:

The Society of Exploration Geophysicists and its colleagues in the republics which formerly composed the USSR are organizing a major international conference on the utilization of geophysics in resource exploration and development. This Conference and Exposition will be held in Moscow, beginning Monday, July 27 through Friday, July 31, 1992.

The theme for this Conference and Exposition is: **"Geophysics as Applied to Exploration and Development."**

Current plans call for a very special Plenary Session (tentatively scheduled for the Kremlin's Congress Hall) to begin the meeting on the afternoon of Monday, July 27, with two concurrent sessions (one on seismic subjects and one addressing non-seismic subjects) on Tuesday, Wednesday, Thursday and Friday (July 28-31). These technical sessions, along with a full schedule of poster papers and the Exposition, will be held in the city's beautiful Sovincentr International Conference and Exposition Center in the heart of Moscow.

Though political, social and economic uncertainties exist, this vast land represents an incredibly fascinating new frontier with enormous potential for the application of geophysical tools and techniques in both exploration for new fields and the development of existing ones. With this in mind, the SEG and the resource exploration and development community around the world view this as a major event of great historic importance.

We are pleased to issue this official **Call for Papers** for the **SEG/Moscow '92 International Geophysical Conference and Exposition**. Abstracts for both oral and poster papers are being solicited on seismic and non-seismic subjects. Papers will be presented in Russian or English, with simultaneous translation into the other language.

If you are interested in contributing a paper to this Conference, please submit a short abstract, 300 words maximum. Also, please do not include equations or figures. Early action is important since the number of technical presentations will be limited, and interest is expected to be high. Already, more than seventy companies from around the world have indicated their interest in participating in the Exposition.

Abstracts should be sent by mail or facsimile to:

SEG Moscow '92
c/o Society of Exploration Geophysicists
PO Box 702740
Tulsa, OK 74170 U.S.A.
Fax: (918) 493-2074
Phone: (918) 493-3516

If you wish to send your abstract via courier, the street address at SEG is 8801 S. Yale Ave., Tulsa, OK U.S.A. 77036.

The deadline for receipt of all abstracts is **March 1, 1992.** Current plans call for final assembly of the technical program in the second week of March.

We look forward to hearing from you.

Sincerely

Gordon M. Greve

Gordon M. Greve
General Chairman
for SEG

SEG/MOCKBA '92
SEG/MOSCOW '92

International Geophysical Conference and Exposition

Call For Papers

The Society of Exploration Geophysicists, in conjunction with its colleagues in the replublics which formerly comprised the USSR, is organizing a major conference on geophysics in resource exploration and development. This conference and exposition will be held July 26-31, 1992, in the Sovincentr, Moscow, Russia. The technical agenda will include seismic and non-seismic sessions. Meeting participation is expected from around the world.

Deadline for submitted abstracts is March 1, 1992.

If you are interested in participating in the technical program, send a 300-word abstract (no figures or equations please) to the Society of Exploration Geophysicists. Mail abstracts before March 1 to:

SEG/Moscow '92
Society of Exploration Geophysicists
P.O. Box 702740
Tulsa, Oklahoma 74170-2740
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Telephone (918) 493-3516
Facsimile (918) 493-2074

Soviet-American Monograph on Geothermal Energy

To: Patrick Muffler, Hugh Murphy, John Lund
All American Co-Authors

Subject: NewsMemo No. 8
Date: 4 November 1991

The trip to the Saint Petersburg (Leningrad) Mining Institute in October was somewhat difficult and since returning, have been in contact with the three Volume Editors to set our policy, which we have now done.

The problem has been the year we have lost in getting the 26 Chapters underway. During the one-day meeting in Moscow with the Soviet Editors and some of the Chapter Authors, it became clear that more that postal delay was responsible for our lack of 'Hearing' from the Soviet Co-Principal Authors. Hopefully, the means for rapid communication are at hand. On 4 November, I received the first Fax from St. Petersburg (by Satellite) and an Express Mail package with partial manuscripts for Hugh Murphy and Ping Cheng.

Hopefully, the misunderstandings in Moscow have been resolved. Enclosed is a copy of the letter we have Expressed Mailed to SPMI that spell out both our position on getting the writing of the Monograph underway and our concern about the premature coupling of the Chapters to the SGA International Symposium firmed up for 22-28 June 1992. Another point agreed upon was that each side would send its outlines and text in its own language and we are working on the means to assist those who don't have local translation available.

Also enclosed are details of the Symposium, an invitation from Yuri Dyadkin to Attend and a letter from the Soviet Co-Editors with hopes to get our Monograph back in action. Hopefully, each of us should be hearing from our co-author soon. When you receive your first communication from your Co-Author, please let your Volume Editor and me know. Please also let me know if you will be at the Stanford Workshop in January. Perhaps we can have an informal "author's meeting".

I am also enclosing a copy of my Label output with addresses, etc. Please send me any corrections or changes. In closing, let me to suggest to each of us that we look over our Outlines and improve them if warranted. Those who would like to try to present a Draft paper at the Symposium should start the preparation of the Text of the assumed responsible Sections. The Time-Table to have a First Draft for presentation at the Symposium is still Comfortable. The Call for Papers is just going out and additional papers will be accepted, probably right up to the time of printing the "almost" Final Program.

With best wishes,
Paul Kruger

STANFORD UNIVERSITY
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30 October 1991

Prof. Yuri D. Dyadkin
St. Petersburg Mining Institute
21 Liniya, d.2
Saint Petersburg, 199026 USSR

Dear Yuri:

Since returning from the short visit to SPMI and the one-day meeting with the Soviet Co-Editors in Moscow, I have conferred with the American Co-Editors on how to resolve the problem of beginning and completing the preparation of the 26 Chapters of the Monograph. Actually, the problem of the Monograph consists of two separate aspects: (1) the mechanism for preparing the Monograph and (2) the coupling of the Monograph to the SGA International Symposium now fixed for June, 1992. Both of these aspects need to be addressed and resolved.

With respect to the first aspect of the problem, the American Co-Editors believe that it is too late to change the fundamental intent of the Monograph, namely to be a compilation of 26 Chapters prepared by 26 Soviet and American co-authors covering the three main areas of geothermal energy technology as conceived by the two Monograph editors as Task 4 of the SGP-LMI Geothermal Agreement. With respect to the role of the Volume Editors, except for monitoring the progress of the Authors, we believe that the Editors will become active only when the Draft chapter manuscripts have been assembled. In the meantime, we urge you to expedite the initial contact from each Soviet responsible Author to the American responsible Co-Author to complete the Chapter Outline and the assignment of the Sections to be drafted by each co-author. It will be difficult to fix a schedule for completing the Monograph until this initial activity is accomplished.

When the First Drafts of each Volume are assembled, it will be possible for the Volume Editors to evaluate the total coverage and to recommend changes in Volume structure or Chapter content. At that time it should be possible to suggest other Chapters, if needed, or restructuring of Draft chapters or sections.

With respect to the second aspect of the problem, the American Co-Editors believe that it is unfortunate that the SGA International Symposium was set for an early date relative to the achievement of the Chapter Drafts. There is much pressure to uncouple the preparation of the 26 Chapter drafts from the working sessions of the Symposium, unless resolution of the first aspect of the problem occurs very rapidly. As I explained to you during the visit, because of the long time without contact from the Soviet Co-Authors, we are unsure of how many American Authors will be able to make the $3000+ trip to the Soviet Union by June, 1992. In fact, we think only a few will be able to do so. An alternate option might be to have only the Volume Editors prepare general volume papers for the Symposium and remove the pressure of trying to write 26 symposium-quality papers without Soviet co-authors in such a short time period.

With respect to the individual Volumes, I have given the manuscripts of Volume 1, which I received at the Moscow meeting to Patrick Muffler. He joins me in noting that these large individual treatises need to be condensed within the Chapter Outlines, which have yet to be determined and finalized. For Volume 2, I have discussed with Hugh Murphy my meetings with Emil Boguslavsky at SPMI and the need for him to have the Soviet authors, except for Kiryukhin, Dyadkin, and Gendler, initiate contact with the other 7 American co-authors on completing the Chapter Outlines. We agreed that the question of an 11th Chapter for Volume 2 should be deferred until the 10 Draft Chapters are assembled. For Volume 3, I have discussed with John Lund the problems from the Moscow meeting and the plan for Dr. B.M. Kozlov to visit SPMI for re-evaluating the selection of Soviet authors for the 11 Chapters of the volume.

Thus we need to rebuild the momentum generated last year for a successful Soviet-American Monograph. I am sending this letter to you by Express Mail to both your office and home as a test to see whether we can shorten the time period between communications. With my very best wishes to you and the Soviet Volume Editors and Co-Authors,

Yours sincerely,

Paul

ПРОБЛЕМЫ ГЕОТЕРМАЛЬНОЙ
ЭНЕРГИИ
Ленинград, 22-28 июня 1992г.

PROBLEMS OF
GEOTHERMAL ENERGY
June, 22-28, 1992
Leningrad , USSR

ОРГАНИЗАЦИОННЫЙ КОМИТЕТ
ORGANIZING COMMITTEE

2, 21 Liniya,
199026, Leningrad,
USSR

213-61-37
218-86-05
Telex: 121494 LGIP SU
Fax: (812) 213-26-13

Philip M. Wright
Univ Utah Res. Inst.

Dear Colleague,

You are invited to attend the International Symposium on Geothermal Energy organized by the Leningrad Mining Institute and the Soviet Geothermal Association. The Symposium is to take place from June 22-28, 1992. Sponsors and participants include the State Committee on Science and Technique of the USSR, the Academy of Sciences of the USSR, the Union of Scientific and Engineering Societies of the USSR, the State Committee of RSFSR on Sciences and Higher Schools, the Academy of Natural Sciences of RSFSR, the International Geothermal Association and the International Bureau on Mining and Thermophysics.

We welcome your participation in this seminar. We are hoping for a substantial number of foreign scholars.

Sincerely, N. M. PROSKURYAKOV

INTERNATIONAL SYMPOSIUM ORGANIZING COMMITTEE LENINGRAD

Chairman Symposium Committee, Rector of the Leningrad Mining Institute

СОВЕТСКАЯ ГЕОТЕРМАЛЬНАЯ АССОЦИАЦИЯ

СССР 199026 ЛЕНИНГРАД

ПРАВЛЕНИЕ СГА
ЛЕНИНГРАДСКИЙ ГОРНЫЙ ИНСТИТУТ
21 линия, д. 2

Тел. 218-86-52
Телекс 121494 LGIP SU
Телефакс (812) 213-26-13
Телетайп 121595 ВИСМУТ

СЕКРЕТАРИАТ СГА
ПРОБЛЕМНАЯ ЛАБОРАТОРИЯ ГОРНОЙ ТЕПЛОФИЗИКИ
Ул. Беринга, д. 3а

Тел. 355-01-13
Расч. счет 70000606027 МФО 171274
Прибалтийское отд. Промстройбанка Ленинграда
199004, Ленинград, Средний пр., 29

SGA: 91/44 11 October 1991

To: American Colleague-Authors and Editors of the Joint American-Soviet Monograph " Geothermal Energy"

Dear Colleague !

Using the short visit to Saint Petersburg and Moscow by Paul Kruger, we direct to you the concordance with the proposed Outlines of the Chapters and distribution of responsibility for preparation of the specified sections.

Of course, we hope for your comments, additions, or revisions for their attentive consideration and utilization in subsequent effort. We also send some draft texts of specific sections of the monograph.

Agreement of the detailed Contents of the Chapters between Co-Authors is very important for accomplishing our complex work. We are very sorry that by dependence and not dependence from our principle this was not done earlier. Postal and other communications between our countries even now remains very poor, making contact difficult. Notwithstanding, we are assured that by our meeting at the International Symposium in June, 1992, we will be able, in principle, to complete our work. We request our American colleagues also to apply effort to a successful completion of this important for our countries joint work.

With the Very Best Wishes,

USSR Volume Editors: Prof.V.I.Kononov, Prof.A.A.Smyslov, Prof.E.I.Boguslavsky, Prof. O.A Povarov, Dr. B.M. Kozlov

Monograph Editor: Prof. Y.D. Dyadkin, President, SGA

СОВЕТСКАЯ ГЕОТЕРМАЛЬНАЯ АССОЦИАЦИЯ

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199004, Ленинград, Средний пр., 29

СГА - 91/44
от 11.10.91

Американским коллегам-авторам и редакторам совместной американско-советской монографии "Геотермальная энергия"

Глубокоуважаемые коллеги !

Пользуясь коротким визитом в Санкт-Петербург и Москву профессора Паула Кругера, направляем Вам на согласование проекты структуры глав и распределения ответственности за подготовку их отдельных параграфов (секций).

Разумеется, мы ждем Ваших замечаний, дополнений или возражений для их внимательного рассмотрения и использования в дальнейшей работе. Посылаем также проекты текстов отдельных разделов монографии.

Согласование детального содержания глав между соавторами очень важно для завершения нашей непростой работы. Мы очень сожалеем, что по зависящим и не зависящим от нас причинам это не сделано раньше. Почтовая и иная связь между нашими странами и теперь остается очень плохой, затрудняет контакты. Тем не менее мы уверены, что до нашей встречи на Международном Симпозиуме в июне будущего года (1992 г.) мы сможем в основном завершить нашу работу. Просим наших американских коллег также приложить усилия к успешному завершению этой нужной для наших стран совместной работы.

С уважением и наилучшеми пожеланиями

Редакторы томов от СССР проф.В.И.Кононов, проф.А.А.Смыслов,
проф.Э.И.Богуславский, проф.О.А.Поваров,
докт.Б.М.Козлов

Редактор монографии проф.Ю.Д.Дядькин,
Президент СГА

РТП ЛГИ. 17.01.91., з. 8, т. 100 экз. Бесплатно

HOTEL ACCOMMODATIONS

Participants and guests of the Symposium will be offered accommodations at the Mining Institute Hotel. Address:

Leningrad, Vasilievsky ostrov, Morskaya naberezhnaya, dom 15 (close to Hotel Pribaltijskaya).

Costs: single - 95 US dollars per day
double - 135 US dollars per day

Cost includes three meals per day

It is also possible to make reservations at the Hotel Pribaltijskaya.

Costs: double - 160 US dollars per day
suite - 230 US dollars per day
(no meals provided)

INTERNATIONAL SYMPOSIUM ORGANIZING COMMITTEE LENINGRAD

N.M.PROSKURYAKOV

SYMPOSIUM COMMITTEE
RECTOR OF THE LENINGRAD
MINING INSTITUTE

LENINGRAD MINING INSTITUTE
a n d
SOVIET GEOTHERMAL ASSOCIATION

INTERNATIONAL SYMPOSIUM ON GEOTHERMAL ENERGY

June 22-28, 1992

Leningrad , U S S R

Preliminary Information

You are invited to take part in the Interhational Symposium, "Problems on Geothermal Energy".

The wide range of issues to the be discussed at the Symposium sessions will allow participants to gain a greater Understanding of Geothermal Energy Resources evaluation, operations and utilization.

We hope that you will actively participate in the Symposium. By combining our efforts we can make an important contribution to the development of international cooperation. This promises to be a memorable Symposium for all participants and guests.

SYMPOSIUM MISSION AND GOALS

To advance knowledge in theoretical and praclical application of the development of geothermics, geothermal resources evaluation, technology and utilization of thermoelectroenergetics and balneology;

To establish and develop scientific contacts among specialists from different countries;

To improve and expand on the contents of Geothermal Energy, a collection of scientific papers to be published in 1993, in Russian and English.

MAIN DISCUSSION TOPICS

1. Geotemperature Fields and Geothermal Resources;
2. Technology of Geothermal Energy and Fluids Extraction;
3. Utilization of Geothermal Energy and Thermal Water.

CALL FOR PAPERS

Papers are solicited in all aspects of theoretical and applied Geothermics, Geothermal Technology, Geothermal Energetics and Balneology. In order to publish abstracts before the Symposium, the authors should submit brief summaries (not more than one page, approximately 300 words, including the title of paper and the names of the authors) to the Organizing Committee before March 15, 1992.

For More information, please write to:
USSR, 199026, Leningrad, 21 Linia, Dom 2, Leningrad Mining Institute. Phone 2136137, 2188460. Telex 121494 LGIP SU
Fax (812) 2132613. All correspondence should be sent to the above address or to the foreign Co-Chairman of the Program Committee:
Prof. Paul Kruger, Civil Engineering Dept.of Stanford University.

STANFORD CA 94305, USA
Telex 372871 STANFORD STNU
Fax 415/725-86 62
(415)725-20 99

Authors will be informed it their papers have been accepted by February, 1992.

CULTURAL PROGRAM

Participants and guests of the Symposium are cordially invited to participate in our cultural program. Leningrad, one of the most beautiful cities in the world, is famous for its museums, theatres, outstanding architecture and monuments. Its environs are of great historical and artistic value.

Leningrad is most pleasant in June, the month of mild white nights (20-25°C).

PEGISTRATION FEE

The registration fee for Symposium participants is $ 250 and $ 125 for accompanying persons. The registration fee covers: organization of the Symposium; editing and sending abstracts, a 3-Volume collection on "Geothermal Energy", visits to museums and theatres, supper on the first evening and a farewell dinner.

ПРОБЛЕМЫ ГЕОТЕРМАЛЬНОЙ ЭНЕРГИИ

Ленинград, 22-28 июня 1992г.

PROBLEMS OF GEOTHERMAL ENERGY

June, 22-28, 1992
Leningrad , U S S R

ОРГАНИЗАЦИОННЫЙ КОМИТЕТ ORGANIZING COMMITTEE

2, 21 Liniya,
199026, Leningrad,
USSR

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218-86-05
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Fax: (812) 213-26-13

APPLICATION FORM

First name, last name.......................................

Post..

Degree..

Name of institution...

Mailing address..

Telephone.............Telex.........Telefax................

DATA FOR VISA SUPPORT:

Date of birth.........................Sex................

Private address..

Telephone (privat)..............Pasport number.............

Country...

Terms of stay in the USSR (arrival/departure dates).........

....

First name, last name of accompanying person and data for visa support...

....

....

....

Title of report...

....

HOTEL RESERVATION:

Mining institute Hotel
(three meals a day provided)
0 single - 95 $
0 double -136 $

Pribaltijskaya Hotel
(no meals provided)
0 double - 160 $
0 suite - 230 $

Date.........................Signature......................

ПРОБЛЕМЫ ГЕОТЕРМАЛЬНОЙ ЭНЕРГИИ
Ленинград, 22-28 июня 1992г.

GEOTHERMAL' ENERGY
June, 22-28, 1992
Leningrad, USSR

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SPMI

TOURS

Offered for Participants of the

INTERNATIONAL SYMPOSIUM ON GEOTHERMAL ENERGY

June 22-28, 1992

Tour 1: St. Petersburg - Crimea - Moscow
- 29 June - Departure for Crimea - Cultural program (Bakhchiserai, Simferopol)
- 30 June - Scientific excursion
- 1 July - Cultural program (South Shore)
- 2 July - Departure for Moscow
- 3-4 July - Cultural program (Moscow)
- 5 July - Cultural program (Moscow) - Departure

Tour 2: St. Petersburg - Tallinn - Moscow
- 29 June - Departure for Tallinn - Cultural program (Tallinn)
- 30 June - Cultural program (Tallinn)
- 1 July - Cultural program (Tallinn)
- 2 July - Departure for Moscow
- 3-4 July - Cultural program (Moscow)
- 5 July - Cultural program (Moscow) - Departure.

Tour 3: St. Petersburg - Kiev - Moscow
- 29 June - Departure for Kiev - Cultural program (Kiev)
- 30 June - Cultural program (Kiev)
- 1 July - Cultural program (Kiev)
- 2 July - Departure for Moscow
- 3-4 July - Cultural program (Moscow)
- 5 July - Cultural program (Moscow) - Departure

Price of the tours per person (in U.S. Dollars)

Tour 1	$490.00
Tour 2	$420.00
Tour 3	$440.00

Prices include:
1. Transportation within the country
2. Hotel accommodation
3. Three meals per day
4. Bus service
5. Cultural programs

To participate in any of the tours, please contact the Organizing Committee by March 1, 1992:

President, Organizing Committee
Rector, St. Petersburg Mining Institute
N.M. Proskuryakov

INTERNATIONAL SYMPOSIUM
ORGANIZING COMMITTEE

Veatch, Ralph E.
Amoco Prodn Res. Center
P.O. Box 3385
Tulsa, OK 74102
918+660-3309
Chap.2.6
Fax: 918+660-4175
LMI

⇒ Wright, Phillip M.
Univ. of Utah Res. Inst.
391 Chipeta Way, Ste C
Salt Lake Cty, UT 84108
801+524-3422
Chap.1.4
LMI
Fax:

These are my Address label listings
(first 4 lines, 24 spaces)
Please check your listing
and return with any corrections
or revisions to address or phone
numbers.

Thank you,

Paul Kruger

Soviet-American Monograph on Geothermal Energy

To: Patrick Muffler, Hugh Murphy, John Lund
All American Co-Authors

Subject: NewsMemo No. 7

Date: 11 July 1991

The trip to the Leningrad Mining Institute for 30 June was scratched at DOE so we are falling even further behind. The earliest next dates are September-October, but several events at LMI have occurred which makes this NewsMemo important to distribute right now.

The meeting of the Soviet Co-Authors took place at LMI during late May (have received a copy of the Agenda). It appears that the Soviet Co-Authors have accepted the terse Chapter Outlines, in general, and that changes will be made by individual pairs of Co-Authors. Therefore, it is strongly recommended that each of the 26 U.S. Authors initiate the preparation of the Monograph chapter. It may be awhile before individual contacts begin. I will offer, if the trip to LMI does materialize for Sept-Oct, to carry any drafts with me for delivery to the respective Co-Author.

It also appears that the presentation of the 26 Chapters will be part of the Program for the SGA International Symposium, now scheduled for 22-28 June 1992. Therefore, it is also strongly recommended that plans be initiated to attend the Symposium. 'How' is yet a problem, but the dates look firm at this time. Enclosed is a copy of the cover sheet of the Preliminary Announcement, translation of the details will be in the next NewsMemo.

Paul Kruger

LENINGRAD MINING INSTITUTE
and
SOVIET GEOTHERMAL ASSOCIATION

with support and participation of

State Committee on Science and Technology AS USSR
Union of Science and Engineering Societies USSR
State Committee on Science Affairs and Higher Schools RSFSR
Academy of Natural Sciences RSFSR
International Geothermal Association
International Bureau of Mining HeatPhysics VIT

Organize

INTERNATIONAL SYMPOSIUM ON PROBLEMS OF GEOTHERMAL ENERGY

22-28 June 1992
Leningrad, USSR

PRELIMINARY ANNOUNCEMENT

ЦЕЛИ И ЗАДАЧИ СИМПОЗИУМА

- Углубление знаний и обобщение научных и практических результатов развития геотермии, оценки геотермальных ресурсов, технологии их освоения и использования в теплоэнергетике и бальнеологии.
- Установление и укрепление научных контактов между специалистами из разных стран и организаций.
- Улучшение и расширение содержания коллективной монографии "Геотермальная энергия", издаваемой в 1993 г. на русском и английском языках.

ОБСУЖДАЕМЫЕ ПРОБЛЕМЫ

соответствуют тематическому содержанию трех томов этой монографии:

1. Геотемпературное поле и геотермальные ресурсы
2. Технология добычи геотермальных флюидов и энергии
3. Использование геотермальной энергии и термальных вод

ЗАЯВКИ НА УЧАСТИЕ И ДОКЛАДЫ СИМПОЗИУМА

рекомендуется подать до 15 ноября 1991 г. Принимаются заявки на доклады по любым аспектам теоретической и прикладной геотермии, геотермальной технологии, геотермальной энергетики и бальнеологии.

Для публикации тезисов докладов на русском и английском языках перед Симпозиумом авторы должны представить их в объеме не более одной страницы (примерно 300 слов, включая название, фамилию и организацию автора) в Оргкомитет с авторским переводом на другой язык до 15 марта 1992 г.

КУЛЬТУРНАЯ ПРОГРАММА

приглашает участников и гостей в театры и музеи, на экскурсии по архитектурным ансамблям и историческим памятникам одного из красивейших городов мира в период знаменитых "белых ночей" (температура 20-25°C), а также в тематические экскурсии:
- Москва-Ярославль -3дня, 400 руб;
- Крым с прогулкой по Черному морю – 4 дня, 450 руб;
- Тырныауз – Эльбрус – 4дня, 480 руб;
- Пушкинские горы- Псков – 2 дня, 200 руб.

Выбранный тур и гарантия его оплаты указывается в заявке на участие в Симпозиуме до 15 ноября 1991 г.

РАЗМЕЩЕНИЕ В ГОСТИНИЦЕ

также указывается в этой заявке с гарантией оплаты выбранного варианта:
- городские гостиницы, одноместный номер – до 25-30 руб/сут.
- то же, двухместный номер – по 15 -18 руб/сут.
- гостиницы ЛГИ, номер на 2-3 человек – по 10 руб/сут.
- комнаты на 3 – 4 человека в общежитии – по 3-5 руб/сут.

РЕГИСТРАЦИОННЫЙ ВЗНОС

покрывает вручаемые каждому участнику три тома монографии, Карту геотермальных ресурсов СССР, сборник тезисов, расходы на культурную программу и организацию симпозиума составляет 400 руб, для авторов заказных докладов и гостей 200 руб. (члены Оргкомитета освобождаются) и переводится на счет Советской Геотермальной Ассоциации 70000606027 в Прибалтийском отделении Промстройбанка Ленинграда (199004, Средний пр., 29, МФО 171274 до 1 апреля 1992 г., а посланный после этого срока или вносимый при регистрации увеличивается на 20%.

МЕСТО ПРОВЕДЕНИЯ И АДРЕС ОРГКОМИТЕТА СИМПОЗИУМА

Ленинградский горный институт. 199026 Ленинград, 21 линия, 2.
Телефоны 2136137, 3550112, телекс 121494 LGIP US
Факс (812) 213-26-13
Председатель Оргкомитета, Ректор ЛГИ член-корр. АН СССР
Н.М.Проскуряков

<u>Sat 11 May 91</u>

15:25 - Paul Kruger

Received my fax of 5/11/91, and agrees with most of my points. **An overriding problem is communication with the Soviet Union.** On 11 Jan 91 Yuri Dyadkin sent an (important) letter to Paul, one copy to Paul's home and one copy to the Dept. of Civil Engineering at Stanford); the letter arrived 01 May! Paul has been trying to call Dyadkin since then, but has been unable to get through to Leningrad. Unless we can find some better way of communicating, the US-Soviet Monograph is in deep trouble. Paul stated that there is a new direct-dial phone line to the Soviet Union, but only to Moscow, and apparently Kononov (in Moscow) has access to a fax machine (but Paul does not know the number). Federal Express is not the solution; there is a 10-day delivery time, and at a prohibitive cost.

United States Department of the Interior

GEOLOGICAL SURVEY

TAKE PRIDE IN AMERICA

5/11/91 - 15:10 PDT

TELEFAX COVER SHEET

To: Paul Kruger

FAX: 493-4284
TEL: 493-4284

From: Patrick Muffler
USGS
Menlo Park, CA
FAX: 1-415-329-5110
TEL: 1-415-329-5239

Number of pages including this one: 2

Subject: Response to your faxes of 21 April 91 and 22 April 91 and your NewsMemo No. 6 dated 30 April 91

Apologies for being late, but I have had no time to do more than glance at your faxes and the NewsMemo until this weekend. I have received nothing from the Chapter Authors of Volume 1 in response to your 30 April 91 NewsMemo, so this response represents only my (initial) reactions.

1. p. 2-3 of your translation of the "Memorandum of Invitation ***": This schedule for the monograph is obviously impossible. It is already May 1991, and the Americans have yet to get reactions from the Soviets to the outlines that each American chapter author supplied in the fall of 1990. Yet the schedule indicates that by May 1991 there is to be *"completion of chapter manuscript and its translation, accord between co-authors"*! Most of the US authors are very busy people and are in a very poor position to play catch-up this summer. Fortunately, there appears to be a lot of slop between July 1991 and March 1992. **It appears obvious that one of your primary jobs in Leningrad is to negotiate a realistic schedule.**

2. ¶ 2 of last page of the "Memorandum of Invitation ***":Are any of the American authors in a position to translate their contributions in English into Russian? I certainly am not. **How is this translation to be accomplished?**

#212

3. Protocol for conducting International Symposium "Problems in Geothermal Energy": I continue to suspect that the proposed International Symposium in Leningrad and the Crimea in 1992 is desperately optimistic. Do the Soviet's have any idea what it takes to put together an International Symposium? Not only the "in-country" efforts, but all the effort abroad to prepare the contributions, get financing and permission to attend, etc., etc. One year is hardly enough lead time. Plus the Symposium is only two years after Kona; international travel is hard enough every five years. And the whole thing is exacerbated by the exceedingly uncertain political situation in the Soviet Union. **This Crimea meeting has to be a lot more realistic and firm** than it is now if you hope to get significant participation from the American authors, much less people outside the monograph.

4. p. 3-4 of the Protocol for conducting International Symposium "Problems in Geothermal Energy": In note that John Garnish is listed as a Co-Chairman, but I know from having spent nearly a week with John in Pisa in late April that he knows little about the matter. Similarly, the assumption that the Symposium will get "support" (financial?) from the International Geothermal Association is nothing more than an assumption. The IGA is struggling to keep afloat financially (particularly because of difficulties with GRC), and it is highly questionable whether any financial support for a meeting in Crimea will be forthcoming.

5. I doubt that we can get any action whatsoever out of the American authors for volume 1 until we get some response to the draft outlines supplied to the Soviets 6 months ago. Therefore, **a priority item for you in Leningrad is to extract these responses.** Then maybe we have a chance of energizing the American authors.

Please call if you have any specific questions. I plan to be out of the office from Friday 17 May until Monday 03 June, in the office until Monday 17 June, and then out again until Monday 01 July. Several uncertainties out of my control (including scheduling traffic school!) could change things.

Paul Kruger / Soviet Meeting   9 May 91

GRC - Anderson, Wright, Koenig, Lund
NGA - Jim Hanson + Board JK
IGA - Wolfe. + Board JK
USGIC - Jim Hanson / Chairman

April/May 92 - in the Crimea - what Russians want

- 1975 Geoth Conf in San Francisco / UN
Yuri Dyadkin - Both Dyadkin & Kruger worked on nuclear / geothermal
- Dyadkin lectured at Stanford. Signed a 5-yr agreement for Leningrad M.I. Tech Agree -
- 4 Tasks in this agree. Open USSR/Stanf - others.
- Proposal for $ for these tasks.

Tech Transfer to Re[illegible]

Tasks:

1. HDR task - Russians have been working on their own. They created their own penny-shaped crack. So task 1 is CONT/CAL w/ CONT seismic monitoring. Elbrus active area.

2. Task 3 - ~~petroleum~~ fossil / geoth - burn coal in place; remove heat w/ geoth technology

Translation is a prob. Paul call Keller?

- want us to look @ spent oil fields as sources.

Task 4 - Underway -

Soviet / American Money on Geoth Energy this will get done by "labor of love" if needed.

Soviet Geoth Assoc - $10 dues sent to Paul.

Task 5

- crimea - breadbasket + vacation [illegible]. Plans are for nuc plant, which people don't want. Locals want to replace nuc w/ gas, replace water heating w/ geoth.

- SGA = Soviet Geoth Assoc has educational, lobbying, commercial in one.

- SGA wants to look like GRC re bulletin, etc.

- Task 5 -

Provide tech assist

LANL - fracturing

OIT - direct-heat mangmt

- Joint Soviet / US Cos [illegible] venture to pursue syst as large-scale commerc ventures

USSR/Stanford agreement is opened up to any US co, institution etc.

- When Russians invite you to visit, they will pay all expenses beyond ~~our~~ Moscow airport. They expect the same when they arrive here.

- David Hulse will be co-chair
- Gorody represents IGA as co-chair

- June meeting: Kruger, Laird, Duchane, Murphy

- ~~DAN~~ pre-proposal given to Sen. Domenici thru Paul Gilman.

- Russians don't have $. For Geneva, they want
  1. Capital for 100 wells
  2. Technology

(a) IGA - is in process of forming an Assoc of SGA.
(b) for NGA - poll board. This may be the primary association.
24 June is day Paul leaves for England/USSR

Soviet-American Monograph on Geothermal Energy

To: Patrick Muffler, Hugh Murphy, John Lund
All American Co-Authors

Subject: NewsMemo No. 6

Date: 30 April 1991

On 18 April 1991, I received Six letters from LMI postmarked from 11 Dec 90 through 12 Feb 91. These contained news about the new hydrofracturing success at Tirniauz, the development of the Soviet Geothermal Association plans for an International Symposium for 1992 involving all U.S. Co-Authors, and the first NewsMemo from Prof. Dyadkin to the Soviet Co-Authors, the last written sometime around November-December.

The three U.S. Co-Editors join me in distributing a copy of my very Rough translation of Yuri's memo for your information and review. The Editor's trip to LMI (by two or three of us) is shaping up for the first week in July, when it appears we will finally get the arrangements sufficiently nailed down that we can proceed with the Monograph preparation, in spite of the terrible postal situation.

What seems to be needed now is our comments, rebuttals, if any, and constructive suggestions on how to get on with the job. I am planning to leave the U.S. on 24 June and have arranged to confer with the three Co-Editors as the trip develops. It would be very useful now, to avoid later confusion and misunderstanding, if we presented a firm mode of preparing the Manuscript and our thoughts on how to participate in the SGA Symposium. I am asking each of you to review the "Instructions" to the Soviet Co-Authors, keeping in mind the more rigid political environment with so many involved Ministries and Institutions in the USSR and provide me and your Editor with your thoughts on how best to arrange for individual Chapter agreement and correspondence. We may need to use any kind of electronic or telephone mail available (will look into this while there) and confirm arrangements on how mutual translations will take place.

I plan to carry with me a complete set of U.S. Co-Author Suggested Outlines and Effort Distribution. So now would be a good time to review your own Outline sheet and send me any changes in outline, distribution, or contact numbers (especially Fax and Telex). I am still trying to raise some funds to cover communication and translation costs (tho it is Tough!). However, in spite of the long postal delay in getting going, Prof. Dyadkin's NewsMemo is encouraging, if he can cut though the Soviet bureaucracy, that there will be a Soviet-American Monograph! Although the final details still need to be worked out, I would suggest strongly that we begin preparation of the Chapters along the Suggested Outlines, in that I don't feel after all the Rhetoric is over, that the Chapter structure will change very much.

SGP-LMI Geothermal Agreement
Task 4
Soviet-American Monograph

Rapid Translation
Memorandum of Invitation
to

RESPONSIBLE AUTHORS
SOVIET-AMERICAN MONOGRAPH
"GEOTHERMAL ENERGY"

Memorandum No. 1

The Soviet-American monograph "Geothermal Energy" is being prepared for publication in 1993 in Russian (Nedra, Moscow) and in English (Stanford Press, Stanford) under Technical Task No. 4 of the Geothermal Agreement on collaboration between the Leningrad Mining Institute and Stanford University in the field of geothermal energy development.

Chief editors: Prof. Yu.D. Dyadkin (LMI)
Prof. P. Kruger (SU)

Scientific volume editors:

Vol. 1 RESOURCES, 20 auth.l
for USSR - Prof. V.I. Kononov (GIS)
Prof. A.A. Smislov (LMI)
for USA - Dr. P. Muffler (USGS)
Commitment for publication of volume in "Nedra" (20,000 rubles provided by Scientific Council on Problems in Geothermics AS U (Moscow); American publication - by self-support

Vol. 2 EXTRACTION (Technical recovery), 20 auth.1
for USSR - Prof. E.I. Boguslavsky (LMI)
Dr. V.A. Vaciliev (ENIN)
for USA - Dr. H. Murphy (LANL)
Commitment for publication of volume in "Nedra" (20
provided by Soviet Geothermal Association (Leningr
publication - by self-support

Vol. 3 UTILIZATION, 20 auth.1
for USSR - Prof. O.A. Povarov (MEI)
Dr. G.M. Gaidarov (VNIPI
for USA - Prof. John Lund (GeoHe
Commitment for publication of volume in "
provided by VNIPIGeoTerm (Makhachkala);
by self-support.

As Responsible Authors of the 26 chapters of the Monograph are invited well-known specialists of the USSR and USA. You are invited as a Responsible Author of a Chapter.
Your American Co-Author is:
Address:

In September-October of this year, I made contact with the council of Editors of the Volumes and Co-Authors of several chapters. With Prof. Paul Kruger we discussed problems of preparation of the Monograph at Stanford, Santa Rosa, Klammath Falls, Albuquerque, Santa Fe, Los Alamos, Los Angeles, New York, and Washington. With American Volume Editors and several chapter Authors (P. Muffler, H. Murphy, J. Lund, M. Gulati, J. Rowley, B. Robinson, P. Lienau, K. Rafferty, R. Schoemachers). These discussions permitted a more accurate definition of the structure and composition of the monograph authors (enclosed), although, of course, in the process of working, further refinements will be possible. Corresponding functions of the Responsible Authors of the chapters, recommendations on their contents, and the schedule of the work follow:

1. <u>October 1990</u> - Agreement on structure of the volumes and authors of the chapters;
2. <u>Nov-Dec</u> - Preparation of the prospective chapter (1-2 pages), agreement with volume editor and co-author, initiation of contact of co-authors (telephone, fax, telex, mail);
3. <u>Jan-Mar 1991</u> - Preparation of Russian chapters, translation into other language and submission to volume editors;
4. <u>April</u> - Working conference of chapter authors with volume editors separately by country (USSR - at LMI). Agreement on controversial questions on distribution of material between chapters;
5. <u>May</u> - Completion of chapter manuscript and its translation, accord between co-authors;
6. <u>June</u> - Working meeting of the volume editors from the USSR and USA with local authors in Leningrad (LMI) - confirmation of contents of the chapters, foreword and prospectus of the volumes, agreement of editors in both languages for publication in the USSR and USA and conclusion of publication agreement.
7. <u>Jul 91-Mar 92</u>- Finishing and revision of chapter manuscripts in both languages or reciprocal editing translations;
8. <u>April 1992</u> - International Symposium on Problems in Geothermal Energy, Crimea, with invitation to all Editors and chapter Authors as speakers at morning Sessions of the three thematic working days of the Symposium (per the three Monograph volumes); information on appearance at evening thematic Sessions of other participants at the Symposium from USSR and other countries

included with referenced authorship in sections "Discussion" in the corresponding Monograph chapters;

9. May - Completion of editing and revisions of chapter manuscripts with incorporation of materials presented at the Symposium;

10. June-July - Submission of final manuscript in Russian and English to the designated publishers in the USSR and USA.

For equal size of the volume and with differing number of planned chapters, the size of each chapter should be: for Vol. 1, 4 author-lists; for Vols. 2 and 3, approximately 2 author-lists, taking for 1 author-list 25 pages of double-spaced manuscript text, for corresponding reduction of text pages taking into account inclusion in manuscript of illustrations (5-20 per chapter) and bibliography (not more than 30 per chapter).

Since the Monograph is a Soviet-American publication and with authors only from the USSR and USA, it is natural that in each chapter the greater weight should be on the general results of investigation and experience mainly in these two countries, and literature from other countries are also to be included, but should be given greater brevity.

In each chapter expediently introduce a section on "Discussion", allotting 4-6 pages for original materials presented at the planned Crimea International Symposium in 1992. However it is not necessary for all chapters to have the same structure and section headings (For example, 2.1 Introduction; 2.2 Experience in the USSR; 2.3 Experience in the USA; 2.4 Other countries; 2.5 Discussion; 2.6 Conclusions; 2.7 References). All of these parts should be in each chapter, but its outline could be varied. The structure of the chapter, titled sections, allocation between Soviet and American Co-Authors should be confirmed among themselves in November-December 1990. Naturally, it should not be necessary for Soviet or American Co-Authors to write the whole chapter alone. Hopefully, the Co-Authors should resolve these questions by themselves and parts of chapters by level of competence and availability of pertinent materials. For the goal of a high quality publication it will be necessary to refer the resolution of problems to "third-parties" from highest competent specialists in the USSR and USA.

Although such "procedure" raises the quality of the chapter, it could hamper the management of the work, it follows that it should not be misused. In any case, the quality of the chapters, responsibility for it rests with the Soviet and American Responsible Authors and volume Editors.

In practice, all chapters could and should touch upon its own diversity, pertinent to the geothermal energy questions which are given dedicated sections in chapters of the monograph. Therefore each author should keep in mind the contents of the other chapters of his and other volumes, to resolve, in whatever degree it follows going deeper in the subject appearing in another chapter. However, if the author believes that he is providing very important information, by such "extraneous" subject, he should propose this information to the responsible author of the chapter where it might be better included without restricting the authorship rights. Complex questions of material distribution by chapter should be referred to the pertinent volume editor.

A function of the Responsible Author is to carry out not only translation of his own text into the other language, but also literary editing of the translation to the "foreign" language presented by the co-author of his own text.

It is very desirable that all chapters of the Monograph be written in the style of scientific generalization. That is concrete factual materials, quantitative characteristics, tabulated digests should be used only for illustration of explanatory technical positions, mechanisms, principles. It is doubtful whether it is appropriate for cumbersome mathematical transformations, detailed descriptions without logical consequences, nor argumentive affirmations. The Monograph should not repeat handbooks or textbooks, nor appear to be a scientific-popular text, and even more so - an advertising document. However, it is doubtful whether it should strive to excess for uniform style (certainly, dimensional units should everywhere conform to system "SI", and magnitudes in all chapters be desirably designated alike). In other aspects, it would be better if the reader of each chapter would be offered the possibility of feeling and appreciating the originality personality of the author.

Obviously, we should get started on this extremely complex work. But with full confidence that together we will manage. This will bring to each of us deep satisfaction from participating in this real activity and absolutely strengthen friendly creative contact of Soviet and American enthusiasm for geothermal energy.

Chief Editor
Prof. Yu.D. Dyadkin

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Department of Civil Engineering

Terman Engineering Center
Stanford, California 94305-4020
Telex 348402 STANFRD STNU
Fax 415-725-8662

Soviet-American Monograph on Geothermal Energy

To: Patrick Muffler, Hugh Murphy, John Lund
All American Co-Authors

Subject: NewsMemo No. 5

Date: 28 March 1991

It seems like Ages since there was something to write about following NewsMemo 4 of 30 November 1990 !

The Set of Proposed Outlines from the U.S. Co-Authors, except for the few address changes, was expressed to LMI on November 1, with the three missing ones forwarded later. We received a revised list of Soviet Co-Authors, but apparently no one has heard from his co-author. With all of the problems in the USSR, it appeared that things might be looking bleak for LMI and the Monograph, but I have just received a long overdue letter from Yuri Dyadkin which implies that things are moving along, but not very fast!

To bring you up-to-date, I am enclosing a copy of the note and my translation of the pertinent sections. It appears that "discussion by mail" is next to useless and that a visit is needed. However I still think we need to get each chapter's Co-Authors communicating and do the "negotiating" concurrently. Thus I plan to answer this letter with a reminder to get responses to our Outlines. But even this will take 6-10 weeks for an exchange of letters, so it may not be possible to initiate the Monograph before this summer. In keeping with the agreement from the October meeting, I will try to carry out the June-July visit to LMI, although we had already felt it was too late to initiate travel plans at this late date.

I will be in touch separately with those invited to LMI for the SU-LMI Tasks 1 and 5 projects. The enclosed letter notes the first HDR project success and apparently the Crimea symposium for 1992 is still On.

Will be back with NewsMemo No. 6 ASAP; in the meantime please continue to send me any corrections to mailing address, telephone number, Fax number, and Telex number, where available. Who knows when the flood of letters will start arriving!

Paul Kruger

28 февраля 1991 г.

Ленинград

Дорогой Паул !

У меня хорошая новость : вчера, 27 февраля 1991 г. в Тырныаузе успешно проведен первый в нашей стране гидроразрыв гранитного массива на глубине 3,7 км при температуре около 200°С и давлении воды после насосного агрегата 60 Мпа, объем нагнетания – всего 85 м³, а при повторении –56 Мпа при 120 м³. При схлопывании трещины и выпуске воды давление до 30 Мпа. Конечно это лишь начало, но похоже, что проницаемость не очень высокая и бояться нечего. Обсудим первый результат и продолжим длительные нагнетания-выпуски и будем оценивать размеры зоны гидроразрыва. Пока результаты близки к расчетным. Подробно напишу дополнительно.

Через неделю выйдет из печати наш Бюллетень СГА №1 Пошлем Вам и теперь уже 11-ти иностранным членам СГА. Поздравляю Джона Лунда ! Его предложение об участии В.Б. Адилова и В. Боголюбова в главе 3.10. направил Г.М. Гайдарову и через В.И. Кононова – Н.В. Барабанову / я не знаком с ним/.

В апреле собираем всех советских авторов глав в ЛГИ – "репетиция " международного Симпозиума 1992 года в ЛГИ – Крыму.

Получил ваши письма от 11 и 17 января... это мое письмо – № 16 ! У писем очень долгие пути... Надеюсь на Ваш приезд в июне. В таких "медленных" письмах обсуждать сложные вопросы просто бессмысленно.

Привет Клавдие и Лукасу !

Ваш Юрий Д. Дядькин

28 February 1991
Leningrad

Dear Paul!

I have good news:

Yesterday, 27 Feb 91 in Tirneaus, the first hydrofracture in the Soviet Union was successfully carried in a granitic massive at a depth of 3.7 km at temperature about 200 °C and hydraulic pressure from the pumping unit of 60 MPa. The injection volume totaled 85 m³, and on repetition - 56 MPa with 120 m³. On collapse of the fracture, the water pressure declined to 30 MPa. Naturally, this is only preliminary, but it looks like the permeability is not very great and it is feared there may be none. We are evaluating the first results and continuing long term injection - discharge and we will measure the size of the hydrofracture zone. At present, the results are close to calculations. In detail, I will write additionally.

In a week, our Bulletin No. 1 of the Soviet Geothermal Association will come from the printers; we will send to you and the now 11 foreign members of SGA.

I congratulate John Lund! His suggestion as participants V.B. Adilov and V. Bogolyubov for Chapter 3.10 was directed to G.M. Gaidarov and N.V. Barabanov to I. Kononov.

In April all Soviet chapter authors will be gathering at LMI - a "Rehearsal" of the International Symposium in 1992 at LMI - Crimea.

By mail are very long travel times... We are awaiting your visit in June. By such "sluggish" letters, discussion of complex questions is plainly nonsensical.

....

Yuri Dyadkin

1991(?)

LABORATORY OF
REGIONAL GEODYNAMICS

The Laboratory of Regional Geodynamics (LARGE) is based in Moscow and received its charter in August 1988 as the first privately owned geological and geophysical company in Russia. The main LARGE activity is oil and gas prospecting.

Taking in consideration that world geological and geophysical community is interested a lot in geology of the Eastern regions of the USSR, LARGE has prepared a number of geotours around Russian "terra incognita".

You could have an unique opportunity to look at the geology and wonderful nature of Kamchatka, Lena river and Koryak ridge.

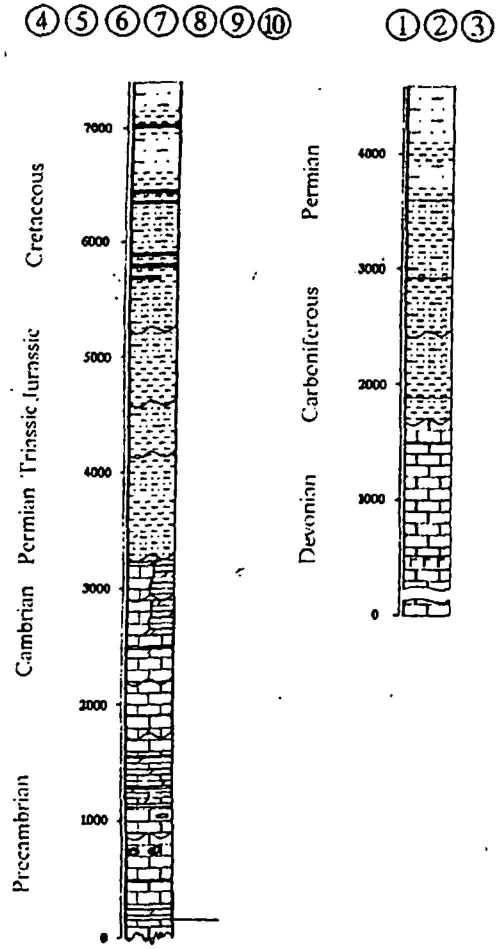
Best regards,

AShilov

Andrey Shilovsky
Managing Director

117485 Moscow USSR
Profsojznaj 102–A
Telex 411700 LARGE 1309
Telefax 200 22 16
Phone 335 05 00

16801 Greenspoint Park Dr.,
Ste 151
Houston, TX 77060, U.S.A.
Office 713 873-6157
FAX 713 875-2605



Practical information.

Departure from Moscow to Tiksy by airplane on Thursday 1 August, return from Tiksy to Moscow, Thursday 14 August. Transportation and accommodation will be by ship. We'll all stay and have meals aboard, and use motorboat to go ashore. Normal temperature at this time of year is around 10 C and we advice the participants to be well equipped with suitable warm field clothes. The field workshop will be lead in Arctic, where the weather conditions are changeable and so the return date could be delayed for 1-3 days.

Cost

The cost of the workshop is 4500 $. It includes all expenses in Moscow and in Yakutya (including air tickets Moscow-Tiksy, Tiksy-Moscow). This sum will be invoiced from IKU or LARGE International before the workshop. All air tickets within the USSR will be reserved in Moscow.

Reservation

Reservation should be adressed to:

— Atle Mork, IKU N-7034 Trondheim, Norway. Phone: +47 7 59 11 00, Fax: +47 7 59 11 02 (aut), Telex: 55434 iku n

— Leo Savostin, LARGE International, J.V. 16801 Greenspoint Park Drive, Suite 151, Houston, Texas 77060 USA. Fax: (713) 875-2605.

Dead line for booking and paying is April 30, 1991.

All the questions for additional information should be adressed to the Organisation Committee: USSR, 117485, Moscow, Profsoyuznaya 102-A

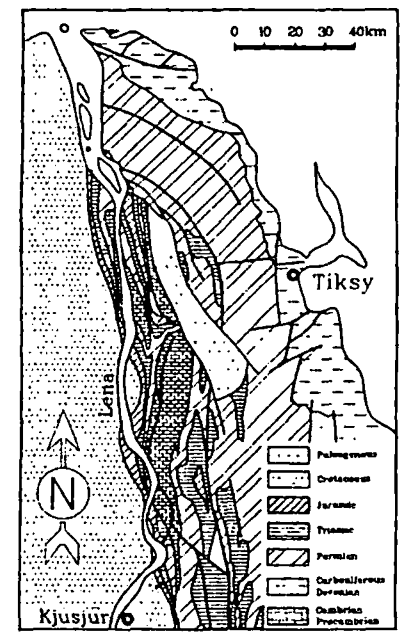
Dr. Egorov A.Y.
Phone: 125-77-11
Fax: 232-03-82

Dr. Savostin L.A.
Phone: 335-05-00
Fax: 200-22-16 large

Aerogeologia
Space aerogeological Expedition-3

Laboratory of regional geodynamics

with the assistance of IKU (Norway) and GEOSOFT (USSR-Austria)
USSR, 117292 Moscow, Krjijanovskogo st. 5 block 3 "Aerogeologia"-3
phone: 125-77-11, fax: 232-03-82
USSR, 117485 Moscow, Profsoyuznaya st. 102-A LARGE,
phone: 335-05-00, fax: 200-22-16 large



STRATIGRAPHY, SEDIMENTOLOGY AND TECTONICS

FIELD WORKSHOP

LENA

1991

Organization Committee:
Egorov A.Y. (Aerogeologia), Savoatin L.A. (LARGE),
Dagys A.S. (IELAS), Drachev S.S. (LARGE)
Novikov A.A. (Aerogeologia), Mironov I.V. (IMGRE)

BACKGROUND

The Kamchatka peninsula is uncommon geological, biological and geographical nature reserve. The bigger part of it is not mastered by people. Many naturalists and trevellers are dreaming to visit Kamchatka.

The nature of Kamchatka is excellent and severe. Kamchatka is one of finest places of the Earth.

There are two large mountain ridges at peninsula: Sredinny Ridge (where there is a highest mountain of Kamchatka - Klutchevskoy volcano, height 4750m) and the East Ridges (Valaginsky, Tumrok, Kumrotch). The ridges are divided by Ozernaya Kamchatka rivers valley - the largest river of peninsular. There are many different animals at Kamchatka. Among them: brown bears, mountain sheeps, reindeers hares and many others. There is a lot of fish in the rivers. Southern part of peninsula is covered by taiga. At taiga there are many rare and relict types of plants.

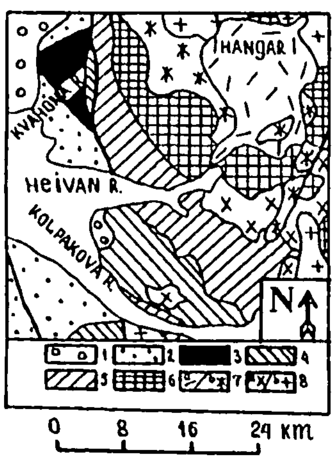
From geological point of view Kamchatka is uncommon too. The peninsula consists of different geological complexes: from precambrian (or paleozoic) to modern age. Our investigations discovered, that peninsula has composed of palaeo-back-arc-basins; palaeo-volcanic-island-arcs; continental rifting and others complexes. There are many active volcanoes at Kamchatka: Klutchevskoy is the highest active volcano at Euro-Asia; Mutnovsky volcano has greatest in the world thermal apanage flow in crater; Koryaksky and Avachinsky volcanoes which you can see from Petropavlovsk-Kamchatsky.

At 1991 we will live at two tent camps. The first camp (map no 1,2) will be located at upper of Kvahona river (right tributary of Kolpakova river). The second camp (map no 1,3) will be locate at the mouth of Moroshechnaya river (coast of Kvachina bay of Ohotsk sea).

The Geotour will be led by G.E.Bondarenko, the geologist in chief of Kamchatsky branch of LARGE International; N.B.Kusnetsov, the geologist of LARGE International and geologists from Kamchatka Geological Serves.

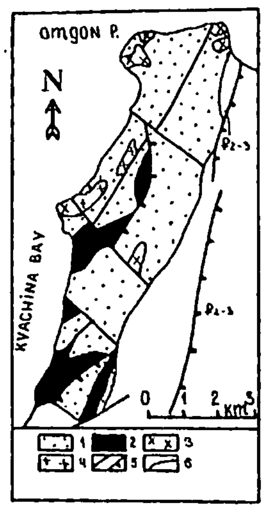
We are inviting to take part in Geotour all naturalists, who are interested in this region and all travellers, who like wilderness and exotic. Our Geotour, also, would be interesting to all broadminded geologists, who are interested in evolution of North-west convergence border of Pacific.

MAP 2



1.-Molasse, KZ; 2.-Turbidate, K_{1-2}; 3.-Effusive-pyroclastic complex, J-K_1; 4.-Ultramafic complex, T-J(?); 5.-Metaturbidate,MZ; 6.-Gneiss, PZ_3-MZ, 7.-a) Effusives, Q; b) Gabbro, N; 8.-a) Plagiogranites,J-K_1; b) Granites, K_2

MAP 3



1. Turbidate, K_{1-2} ; 2.-Effusive pyroclastic complex, J_2-K_1; 3.-Gabbro-diorite, K_2 ; 4.-Granite, K_2; 5.-Faults and thrusts; 6.-Stratigraphic contacts

FIELD PLANS

Geoture is planned as a series of excursions which will be carried from two tent camps. We shall go to the excursion places of and back by helicopter. Excursions themselves will be pedestrian. The part of excursions will be pedestrian only. We will investigate the geological and geographical features of region during the excursion. Our geotour will be extremely interesting for geologist of different speciality and for lovers of journey and nature, who are interested in the history of our Planet.

You will be able to hunt rare animals of Kamchatka for separate pay:for brown bear - 2000 $; probably for mountainous sheep - 3000 $. The lovers of fishing will be able to angler of salmon in rivers for separate pay (near 10 $ for one fish).

We will live in hotel in Moscow and Petropavlovsk-Kamchatsky. We will live in tents at field camps. The nourishment and drinks are for our calculation. The mode of life at field camps is ascetical. It's for courageous and brave men and very different from life in fashionable hotel. But we will do all the best to make this tour exciting.

SHEDULE

SUNDAY, 7. July: arrival to Moscow or to Khabarovsk and accommodation at a hotel.

MONDAY, 8. July: departure to Petropavlovsk-Kamchatsky from Moscow (airport Domodedovo) or from Khabarovsk.

TUESDAY, 9. July: arrival to Petropavlovsk-Kamchatsky. Accommodation at a hotel. At evening - icebreaker.

WEDNESDAY, 10. July: fly from Petropavlovsk-Kamchatsky to tent camp at Kvahona river. The lecture about geological and geographical features of region.

THURSDAY, 11. July: geological excursion to upper of Granatovy stream. The metamorphic complex (biotite gneisses, amphibole biotite gneisses, amphibolites of MZ (J?) age with bodies of ultrabasites. The autoclastic picrites melange zone study. Mafic ksenolites in porphyrites J3-K1 age. During of excursion - the beautiful panorama of Kolpakova river basin.

FRIDAY, 12. July: excursion to paleo-volcano Hangar. We will have a chance to find in large caldera with fine lake after hard ascent. During the ascent we will acquaint with the structure of stratum-volcano and with consisting rocks.

SATURDAY, 13. July: excursion to "Granatovaya mountain". The metamorphic and intrusive complexes. Study of seismodislocations. We will choice the samples of metasomatic rock with large crystals of almandin.

SUNDAY, 14. July: helicopter excursion to Uson volcano caldera. Bathing in lake with warm water. Examination of huggetly sulfur accumulations. Usons caldera is one of finest places of Kamchatka.

MONDAY, 15. July: excursion to Hozgon ridge. Acquaintance with turbidate complex of K2 age and with contact of this complex and paleo - island- arc complex J-K1 age. Very interesting tectonic: complicated folds, thrusts.

TUESDAY, 16. July: helicopter excursion to Geyser valley.

WEDNESDAY, 17. July: excursion to Kvahona and Hultun rivers watershed. The folding structure of metamorphic complex and intrusions of muscovite granite.

THURSDAY, 18. July: helicopter excursion to Mutnovsky and Gorely volcano. We will disembark at the crater of volcano and break the samples of young volcanogenic rocks.

FRIDAY, 19. July: helicopter flight to Moroshechnaya river mouth (tent camp number two). The pillow lavas and agglomeration tuffolava of J2-K1 age study.

SATURDAY, 20. July: excursion along the coastal cliffs. The large syncline of eocene-oligocene rocks study. There are many fossils of Bivalvia and Gastropoda groups. The classic angular unconformity between eocene rocks and turbidate complex of K 1-2 age.

SUNDAY, 21. July: excursion along the coastal cliffs. The olistostrom complex of hoteriv-barremian age and turbidate complex K 1-2 age. The uncommon beauty views: the black cliffs are overhanging over the green water; the birds bazaars; the beautiful cascades.

MONDAY, 22. July: helicopter excursion over the finest volcanos of Kamchatka. The rare possibility to photograph volcano from helicopter.

TUESDAY, 23. July: departure to Petropavlovsk-Kamchatsky. We will take away our baggage to hotel and go to Paratunka (famous health resort with medicinal thermal water). At evening - banquet.

WEDNESDAY, 24. July: departure from Petropavlovsk-Kamchatsky to Moscow or to Khabarovsk. You may take to home the uncommon photographies, collection of rocks and hunting trophies (if you is lucky). Among them you will take home many of agreeable impressions. Welcome to Geoture.

PRACTICAL INFORMATION.

Departure from Moscow to Petropavlovsk-Kamchatsky by airplane on Monday, 8. July, flight no 59 at 11.25. or from Khabarovsk by airplane on Monday, 8.July, flight no ... at .... Return to Moscow 24.July, flight no ... at ... and to Khabarovsk 24 July, flight no ... at .... Transportation within the Kamchatka by helicopter. We will fly to places of excursion and back by helicopter. We will perform the part of excursion by foot from field camps. Normal temperature at this time of year is around 15 C and we advice to participants to be well equipped with suitable warm field clothers. There are many mosquitos at this season and we advice provide oneself with repellent. You must have special rubber foot-wear, because many little rivers and streams at places of excursion. The climate of Kamchatka is very peculiar: the cold winds; rain and snow is normal phenomenon. Therefore the insignificant deflection from detail plans is possible. You will successful get over all difficulties of Geoture at Kamchatka. Our guides who are an experienced field geologist and experts of nature conditions and the animal kingdom of Kamchatka will help you in it.

COST

The cost of the workshop is 5000 $. It includes all expenses in Moscow and in Kamchatka (excluding air tickets). This sum will be invoiced from LARGE International before the workshop. All air tickets inside the USSR will be reserved in Moscow. Note please, that air tickets for foreigners in the USSR have to be paid in the hard currency. Ticket price Moscow - Petr.-Kamch. 500 $ and Khabarovsk - Petr.-Kamch. is approximately 360 $

RESERVATION

Reservation should be addressed to:

Leo Savostin, LARGE International, J.V. 16801 Greenspoint Park Drive, Suite 151, Houston, Texas 77060 USA. Fax:(713) 875-2605.

Dead line for booking and paying is 10 May 1991

All questions for additional information should be addressed to the Organization Committee: USSR, 117485, Moscow, Profsoyuznya 102-A

Dr. Savostin L.A. Phone: 335-05-00 Fax: 200-22-16

LARGE INTERNATIONAL
A GTS JOINT VENTURE
16801 Greenspoint Park Dr., Ste 151
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Office 713 873-8157
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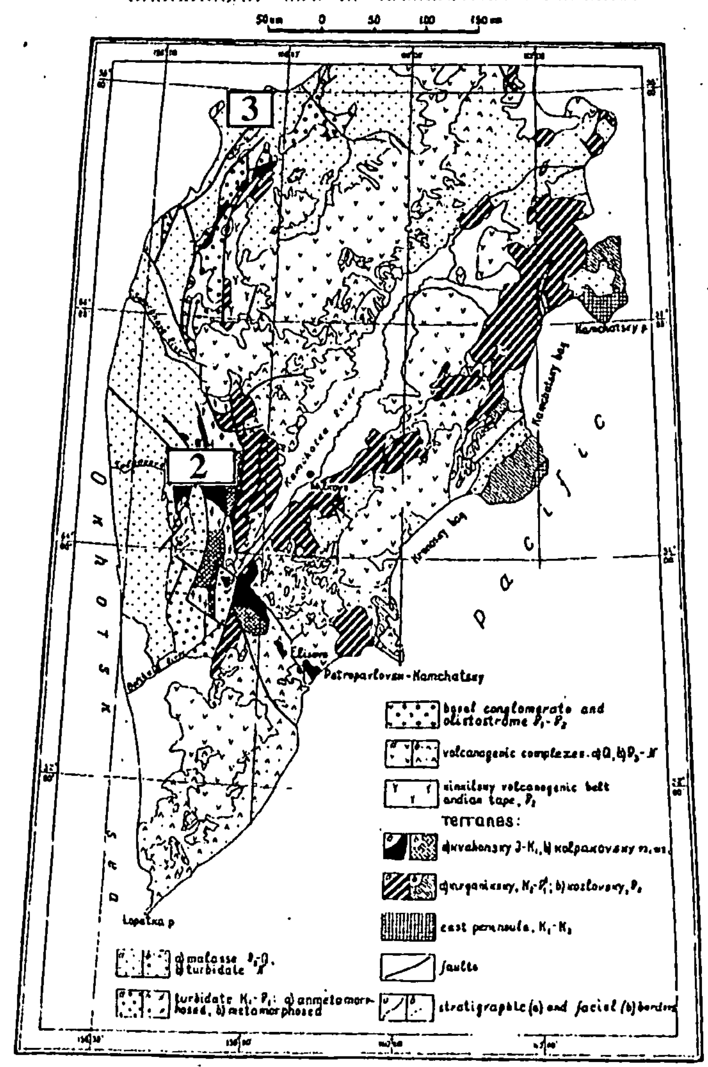
GEOTOUR KAMCHATKA

GEOLOGICAL MAP OF KAMCHATKA PENINSULA



Your way to Chukotka

You can flight to Anadyr from Moscow, Khabarovsk and Providenia airports. Flight # 811-812 Khabarovsk - Niigata (Japan) - Khabarovsk by " JAL " and "Aeroflot". Flight Providenia - Nom (Alaska) - Providenia by "Aeroflot" and "Alaska airlines". The straight flights from Anchorage (Alaska) to Anadyr (Chukotka) will begin in 1991.

Cost.

Registration fee is US $2500. Your expenses in Anadyr and in field camps (including the helicopter) will be paid by "Aerogeologia" and "LARGE Int." All interior air tickets will be reserved in Moscow. Note please, that air tickets for foreigners in the USSR are to be paid in the hard currency. Moscow-Anadyr ticket price approximates US $300, Khabarovsk-Anadyr - US $170 and Providenia-Anadyr US $70.

Our address

Reservation should be addressed to: Dr. Anatoly P. Stavsky - Chief of the Geodynamic Survey Party, Aerogeologia - 3, Krjijanovskogo st. 5, block 3, 117292 Moscow, USSR.

FAX: 200-22-16 box 2536 200-22-17 box 2536

TELEX: 411700 box 2045

Please, show the numbers of boxes after FAX and TELEX.

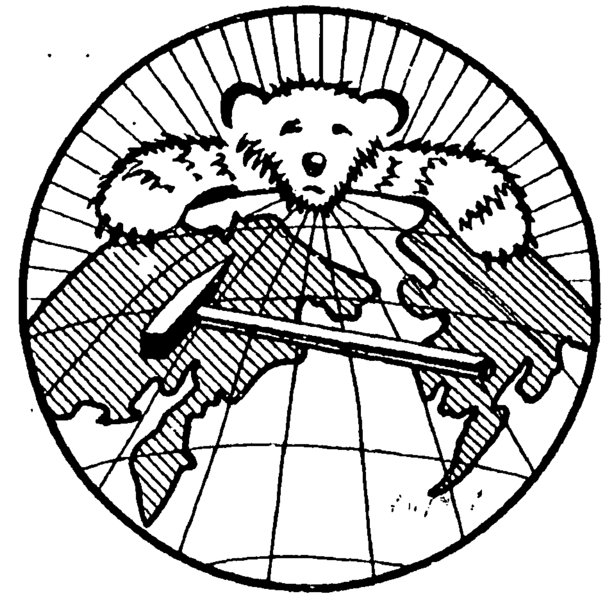
Dead line for booking and paying is 30 april 1991.

Aerogeologia
Space aerogeological Expedition-3

LARGE
Laboratory of regional geodynamics

AEROGEOLOGIA Space aerogeological Expedition-3 USSR 117292 Moscow Krjijanovskogo st..5 block 3 phone 125-25-40 FAX: 200-22-16 box 2536, 200-22-17 box 2536

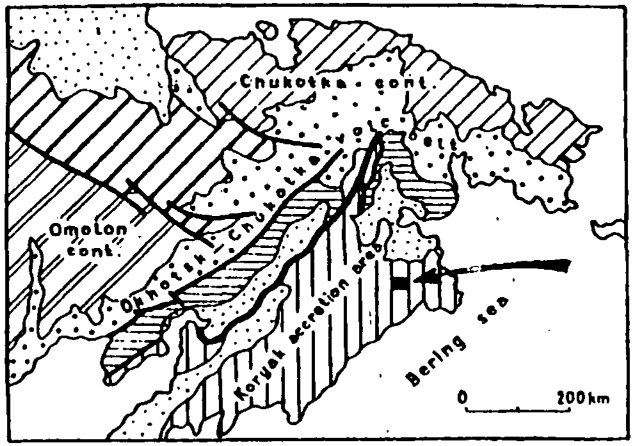
LARGE INTERNATIONAL Laboratory of regional geodynamic 16801 Greenspoint Park Drive, Suite 151, Houston, Texas 77060 USA FAX: (713)-875-2605



THE SECOND INTERNATIONAL GEODYNAMIC FIELD SEMINAR

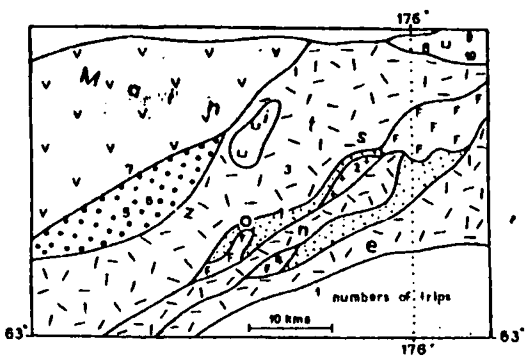
Koryak ridge 20 July - 8 August 1991

Organization Committee:
Anatoly P. Stavsky "Aerogeologia"
Leo A. Savostin "LARGE International"



The Koryak ridge consists of a collage of tectonostratigraphic terranes that have been displaced to varying degrees relative to each other and to Eurasian continent. Accretion to the continental margin occurred mainly from Late Jurassic to Cenozoic time.

The Mainits terrane where the Second International Geodynamic Field Seminar will be held covers a small portion of the Koryak accretion area. It is a well preserved island-arc system of the Callovian-Hauterivian age. Basalts, andesits, dacites, rhyolites, their tuffs, tuffites and siliceous-terrigenous rocks are broadly developed in its northern part. The presence of boninites as indicator rocks of ensimatic island arcs is characteristic of this area. The southern part of Mainits terrane, separated from northern one by Yagel serpentinite melange is built up by graywacke mixtites, tuffaceous sandstones, siltstones and gigantic lump-olistostromes. It is a subduction complex of Mainits island arc produced both due to removal of detrital material from the axial volcanic uplift and due to its tectonic supply from the subducting plate.



Field schedule.

The Seminar is planned as a series of trips and lectures in between. During 10 field trips you will have an opportunity to get acquainted with several unique geological objects inside the Mainits island arc system.

Sunday, 20 July

Arrival in the first field camp. Elgevajam river.

Monday, 21 July.

Lectures "The Koryak accretion area" and "The Mainits island arc".

Tuesday, 22 July.

Field trip 1. The Elgevayam autoclastic melange.

Wednesday, 23 July.

Field trip 2. The Lozov allogenic block incorporated in accretion wedge of the Mainits arc.

Thursday, 24 July.

Field trip 3. Graywacke mixtite complex.

Friday, 25 July.

Field trip 4. Allogenic gabbro-tonalite massif included in subduction complex.

Saturday, 26 July.

Flight to the second field camp. Yagelnaya river.

Sunday, 27 July.

Lecture "Ophiolites of the Koryak ridge"

Monday, 28 July.

Field trip 5. Basalts and ultrabasic rocks of Yagel ophiolite complex.

Tuesday, 29 July.

Field trip 6. Gabbro and sheeted dikes of the Yagel complex.

Wednesday, 30 July.

Field trip 7. Volcano-terrigeneous rocks of Mainits island arc.

Thursday, 31 July.

Flight to the third field camp. Chirynay river.

Friday, 1 August.

Lecture "Ultrabasic and basic rocks in Koryak ridge."

Saturday, 2 August.

Field trip 8. Ultrabasic rocks in Chirynay massif.

Sunday, 3 August.

Field trip 9. Basic rocks in Chirynay massif.

Monday, 4 August.

Field trip 10. Volcano-sedimentary rocks in Chirynay Mountains.

Tuesday, 5 August.

Return to the first field camp.

Wednesday, 6 August.

Lecture "Oil and Gas geology of the Koryak region".

Thursday, 7 August.

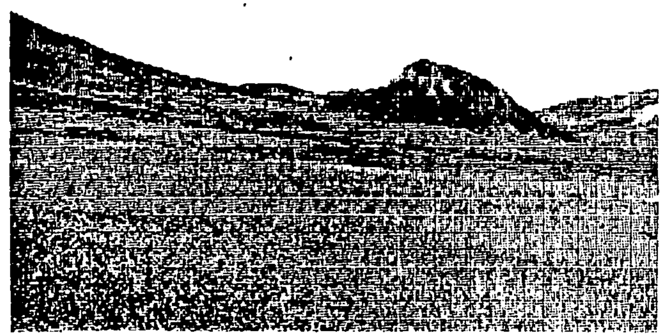
The final discussion.

Friday, 8 August.

Departure from the field camp. Arrival in Anadyr.

9 - 10 August.

Departure from Anadyr.



STANFORD UNIVERSITY
Department of Civil Engineering

Terman Engineering Center
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Telex 348402 STANFRD STNU
Fax 415-725-8662

Soviet-American Monograph on Geothermal Energy

To: Patrick Muffler, Hugh Murphy, John Lund
All American Co-Authors

Subject: News Memo No. 3

Date: 1 November 1990

Enclosed is a copy of the current Full Set of Proposed Outlines expressed to LMI for initiating the Soviet-American Monograph on Geothermal Energy under Task 4 of the SU-LMI Geothermal Agreement. Three of the Outlines have not yet been received. These should be forwarded ASAP to avoid problems for the Soviet Co-Editors.

Please check over your own Outline as formatted for the Set and send me any corrections, revisions, or additions. We will prepare updated versions and send them on (probably to the end of the year) until we start receiving responses from the Soviet Co-Authors. Subsequent changes should be negotiated between the Co-Authors. Please let us know when you first hear from your Co-Author. Keep in mind that there won't be enough time for many exchanges of mail between Co-Authors from now to April '91 when the first drafts are due for final negotiation of publication arrangements in June.

The Proverbial Ball is now in the hands of our Soviet colleagues. It should be quite an experience to see the counter-proposed Outlines, which should really start to set the tone of the Monograph. With the full set of Outlines on hand, each of us should be able to arrive at a mutually satisfactory chapter Outline with agreed assignments to begin the text preparation. I will try to assist anyone with trouble in translating responses in Russian, Please send me (and respective Co-Editor) copies of the responses and your revisions as they develop.

Best Wishes,
Paul Kruger

GEOTHERMAL ENERGY

Joint Soviet-American Monograph

in Three Volumes 1992

Suggested Outlines
by
American Co-Authors*

October, 1990

* for Revision by Soviet Co-Authors

GEOTHERMAL ENERGY

USSR-USA Joint Monograph
(estimated 600 pages in 3 Volumes)
(for publication in 1992)

Chief Editors
Yuri D. Dyadkin (Leningrad Mining Institute, USSR)
Paul Kruger (Stanford University, USA)

Volume 1. Resources (Volume Editors: V. Kononov, P. Muffler)

1.1 Nature of Geothermal Energy
1.2 Heat Flow Distribution and Geothermal Anomalies
1.3 Resource Base and Resources by Type
1.4 Exploration Geosciences (Geology, Geophysics, Geochemistry)
1.5 Prospect Evauation

Volume 2. Extraction (Volume Editors: E. Boguslavsky, H. Murphy)

2.1 Characteristics of Geothermal Reservoirs
2.2 Drilling and Completion of Geothermal Wells
2.3 Well and Reservoir Testing
2.4 Reservoir Diagnostics
2.5 Reinjection
2.6 Stimulation
2.7 Artificial Circulation Systems
2.8 Heat and Mass Transfer Processes in Geothermal Systems
2.9 Management and Economics of Geothermal Fields
2.10 Potential for Magmatic Heat Extraction

Volume 3. Utilization (Volume Editors: G. Gaidarov, J. Lund)

3.1 Spheres of Utilization
3.2 Thermodynamics of Conversion Processes
3.3 Electric Power Plants and Steam Cycles
3.4 Binary Conversion Cycles
3.5 Advanced Conversion Cycles
3.6 Basic Direct Heat Technology
3.7 Municipal Heat Supply Systems
3.8 Industrial Heat and Mineral Extraction
3.9 Agricultural and Aquacultural Heat Supply
3.10 Thermal Water Balneology
3.11 Environmental Aspects of Geothermal Power Engineering

Chapter 1.1
NATURE OF GEOTHERMAL ENERGY

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Telex: tbd

Chapter Outline
(19 Sep 90)

Suggested Responsible Co-Author

I. Definition of geothermal energy (WAD ?)
   A. Sources of geothermal energy
   B. Distribution and movement of geothermal energy within the Earth
II. Geothermal energy in the upper crust
   A. Amount of geothermal energy within the upper few kilometers
   B. Background geothermal flux across the Earth's surface
   C. Regional geothermal regimes
III. Types of geothermal anomalies in the upper crust
   A. Magma bodies
   B. Hydrothermal convection systems
   C. Hot dry rock
   D. Interrelations among magma, hydrothermal convection, and hot dry rock
IV. Geothermal energy and the environment
   A. Types of environmental impacts associated with geothermal developments
   B. Means of mitigating environmental impacts
   C. Comparisons with environmental impacts associated with hydrocarbons and other fossil fuels
V. Speculations on the role of geothermal energy during the 21st Century

Chapter 1.2

HEAT FLOW DISTRIBUTION AND GEOTHERMAL ANOMALIES

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Chapter Outline	Suggested Responsible Co-Author
I. Introduction	(DDB ?)
A.	
B.	
II.	
A.	
B.	
C.	
III.	
A.	
B.	
C.	
D.	
IV.	
A.	
B.	
C.	
V.	
VI. References	(as compiled)

Chapter 1.3
RESOURCE BASE AND RESOURCE BY TYPE

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Chapter Outline
(26 Oct 90)

Outline	Suggested Responsible Co-Author
I. Introduction	
A. Overall objective of chapter	
B. Brief history of topic	
Adaptation of mineral deposits and petroleum terminology	
II. Basic Definitions Illustrated by McKelvey Diagram	(LJPM)
A. Degree of economic feasibility	
1. Resource base	
2. Accessible resource base	
3. Useful accessible resource base	
B. Degree of geologic uncertainty	
1. Identified	
2. Undiscovered	
C. Derived terms	
1. Resource	
2. Reserve	
III. Summary of Past Experience	
A. USA	(LJPM)
1. USGS Circulars 725, 790, and 892	
2. Cascades	
B. USSR	(AAS)
C. World	
1. Tuscany	(LJPM)
2. New Zealand	(LJPM)
IV. Future Expectations and Research Needs	
A. Recovery factor	(LJPM)
B. Undiscovered resources	(AAS)
C. Hot dry rock	(AAS)
D. Magma	(AAS)
V. Discussions and Conclusion	
VI. References	(as compiled)

Chapter 1.4
EXPLORATION GEOSCIENCES

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Soviet CoAuthor: Vladimir I. Kononov — Geological Institute AS, Moscow USSR — Tel: tbd, Fax: tbd, Telex: tbd

Chapter Outline
(21 Sep 90)

Suggested Responsible Co-Author

I. Introduction (PMW ?)
- A. Objective of Chapter
  To review application of geological, geochemical, and, geophysical techniques to regional exploration for geothermal resources
- B. History of geothermal exploratio
  Brief summary of early development, techniques used, philosophy
- C. Summary
  Summary of exploration methods and exploration strategies

II. Review of Regional Exploration Techniques
- A. Classification of techniques and comparison of techniques used to those used for mining and petroleum exploration
- B. Geological techniques of geologic mapping; study of drill samples; age dating; structural studies; geologic interpretation
- C. Geochemical techniques of chemistry of thermal fluids; major,minor, and trace elements in rocks; hydrothermal alteration; isotope studies; fluid inclusions
- D. Geophysical techniques of thermal, electrical, gravity, magnetic, seismic, and seismological methods, and remote sensing

III. Regional Exploration Strategies
- A. Summary of application of geosciences, exploration strategies
- B. Regional area selection with characteristics of geothermal environments (arid, wet, crystalline-rock, volcanic-rock, sedimentary-rock
- C. Regional exploration, exploration process, regional exploration strategies

IV. Exploration Case Studies (also for USSR ?)
- A. Geothermal provinces in the USA; summary of regional exploration in the USA
- B. Exploration of the Basin and Range, western USA
- C. Exploration of the Imperial Valley, southwest USA

V. Future Expectations and Research Needs
- A. Future of geothermal exploration in the USA (PMW?)
- B. (same for USSR ?) (VIK?)
- C. Research needed to improve exploration techniques

VI. Discussion and Conclusions

VII. References (as compiled)

Chapter 1.5
PROSPECT EVALUATION

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Leningrad 199026 USSR

Chapter Outline	Suggested Responsible Co-Author
I. Introduction	(NEG ?)
A.	
B.	
II.	
A.	
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C.	
III.	
A.	
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D.	
IV.	
A.	
B.	
C.	
V.	
VI. References	(as compiled)

Chapter 2.1
CHARACTERISTICS OF GEOTHERMAL RESERVOIRS

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Telex: tbd

Chapter Outline
(28 Sep 90)

	Suggested Responsible Co-Author
I. Introduction	
A. Engineering definition of a geothermal reservoir beyond description of geothermal systems and types from Volume 1	(PK)
B. Brief history of geothermal reservoir engineering	(PK)
C. Basic parameters of geothermal reservoirs	(PK)
II. Summary of Past Experiences	
A. USA history of reservoir development	(PK)
vapor-dominated (e.g., The Geysers, CA)	
two-phase (e.g., Roosevelt Hot Springs, UT)	
liquid-dominated (e.g., Salton Sea, CA)	
geopressured (e.g., Gladys McCall, LA)	
hot dry rock (e.g., Fenton Hill, NM)	
B. USSR history of reservoir development (examples)	(AK)
C. Worldwide experience (e.g., Iceland, Italy, Japan, Mexico, New Zealand, Philippines)	(AK)
III. Current Status of Development	
A. Advances in USA reservoir engineering	(PK)
B. Advances in USSR reservoir engineering	(AK)
C. Summary of world literature	(AK)
IV. Future Expectations and Research Needs	(*)
A. Role of Universities	
B. Role of Research Institutes	
C. Role of National Laboratories	
D. Role of Private Industry	
V. Discussion	(*)
VI. References	(as compiled)

* by exchange of correspondence

Chapter 2.2
DRILLING AND COMPLETION OF GEOTHERMAL WELLS

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Chapter Outline (5 Oct 90)	Suggested Responsible Co-Author
I. Introduction	
A. Objectives of chapter	(BK+JR)
B. Brief history	(BK+JR)
C. Basic definitions	(JCR)
II. Summary of Past Experience	
A. USA data summary	(JCR)
B. USSR data summary	(BBK)
III. Drilling Performance	
A. Drilling effectiveness	(JCR)
B. Rock types and borehole configuration	(BK+JR)
C. Drill bit and core bit performance	(JR+BK)
D. Directional drilling and control	(BK+JR)
E. Summary of critical factors	(JR+BK)
IV. Future Expectations and Research Needs	
A. Drilling strategies	(JCR)
B. Measurments	(BK+JR)
C. Technology issues	(JR+BK)
V. Conclusions	(BK+JR)
VI. References	(as compiled)

Chapter 2.3
RESERVOIR TESTING

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Chapter Outline

Suggested Responsible Co-Author

I. Introduction (MSG ?)
  A.
  B.

II.
  A.
  B.
  C.

III.
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  B.
  C.
  D.

IV.
  A.
  B.
  C.

V.

VI. References (as compiled)

Chapter 2.4
RESERVOIR DIAGNOSTICS

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Chapter Outline
(6 Oct 90)

	Suggested Responsible Co-Author
I. Introduction	(BR+YP)
A. Overall objective and scope	
B. Basic definitions	
C. General characteristics of diagnostic techniques	
II. Diagnostic Techniques	
A. Tracer testing	(BAR)
Desirable characteristics of tracers	(BAR)
Types of tracers	(BAR)
chemical; radioactive	
Interpretation of tracer tests	(BAR)
Field experience	
USA; USSR; world	(BR;YP;BR)
Novel tracer techniques	(BAR)
single-well tracer techniques; chemically reactive tracers	
B. Geochemical monitoring	
Overall description of techniques	(BAR)
Geothermometer measurements	(BAR)
Mixing line analysis	(BAR)
Analysis of field-wide chemical gradients	(BAR)
Isotopes	(BAR)
Minerology	(YMP)
Fluid inclusions	(BAR)
C. Seismic techniques	
Active seismics	(YMP)
vertical seismic profiles (VSP); crosswell tomography	
Passive seismics	(BAR)
monitoring of microearthquakes	
D. Electrical techniques	(YMP)
resistivity measurements; magnetotellurics	
E. Gravity measurements	(YMP)

III. Future Research Needs

A. Tracers (BAR)

Environmentally benign, high-temperature tracers

Fundamental understanding of transport in fractured rock

Demonstration of applicability of novel tracer techniques

B. Geochemical monitoring (BAR)

Remote sampling and measurement capability

C. Seismic techniques (YMP)

High-temperature logging tools

D. Electrical techniques (YMP)

E. Gravity measurements (YMP)

IV. Discussion and Conclusions (BR+YP)

V. References (as compiled)

Chapter 2.5
REINJECTION

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Chapter Outline
(18 Oct 90)

Suggested Responsible Co-Author

I. Introduction
  A. Discussion of the requirements of a reinjection scheme (waste disposal and reservoir management), and difficulties (loss of injectivity and premature thermal breakthrough) (VAV)
  B. Discussion of the basic principle of thermal and fluid transport through porous and fractured media. Tracer tests (RNH)
  C. Overview of current practices in actual geothermal developments (VAV)

II. Summary of Past Experiences
  A. USA (RNH)
  B. USSR (VAV)
  C. World (RNH)

III. Research Directions and Needs
  A. Thermal transfer research (VAV)
  B. Fluid transport and tracer research (RNH)

IV. Discussion and Conclusions (VAV)

V. References (as compiled)

Chapter 2.6
STIMULATION

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Chapter Outline
(5 Oct 90)

Suggested Responsible Co-Author

I. Review of Past Experience (RWV ?)
II. Overview of Possible Stimulation Processes, Methods
  A. Near wellbore methods
  B. Formation penetrating processes
III. Criteria, Methods, etc. for Selecting Stimulation Processes
IV. Application of Stimulation Processes
  A. Hydraulic fracturing
    1. Formation physical, chemical, mechanical considerations
    2. Treatment materials
    3. Treatment design
    4. Treatment application and equipment
  B. Chemical stimulation
    1. Formation physical, chemical, mechanical considerations
    2. Treatment materials
    3. Treatment design
    4. Treatment application and equipment
  C. Mechanical stimulation (explosives, propellants)
    1. Formation physical, chemical, mechanical considerations
    2. Treatment materials
    3. Treatment design
    4. Treatment application and equipment
V. Evaluation of Treatment Effectiveness

Chapter 2.7

ARTIFICIAL CIRCULATION SYSTEMS

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Chapter Outline

(5 Oct 90)

	Suggested Responsible Co-Author
I. Introduction	
A. Objectives of chapter	(YDD)
B. Discovery of hot rock in earth's crust	(HM+YD)
C. Nature and distribution of hot dry rock (petrothermal) resources	(HM+YD)
D. Early proposals for recovering geothermal heat	(HM)
II. Summary of Past Experience	
A. The USA Hot Dry Rock program	(HM)
B. The Soviet Petrothermal program	(YDD)
C. Other programs	(HM+YD)
III. Current Status	
A. USA	(HM)
B. USSR	(YDD)
IV. Future Expectations and Research Needs	(YD+HM)
V. Conclusions	(HM+YD)
VI. References	(as compiled)

Chapter 2.8

HEAT AND MASS TRANSFER PROCESSES IN GEOTHERMAL SYSTEMS

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Fax: tbd
Telex: tbd

Chapter Outline
(3 Oct 90)

Suggested Responsible Co-Author

I. Introduction (PC ?)
II. Fundamental Concepts and Definitions
III. Convective Heat Transfer in Idealized Liquid-Dominated Geothermal Systems
    A. Onset of thermally-induced convection
    B. Onset of thermo haline convection
    C. Finite amplitude cellular convection
    D. Convective heat transfer about intrusives
IV. Boiling Heat Transfer in Idealized Vapor-Dominated Geothermal Systems
    A. Is a liquid layer overlying a wet-steam and dry-steam zone gravitationally unstable?
    B. One-dimensional counterflow of steam and liquid
    C. Cellular convection in a vapor-dominated geothermal reservoir
    D. Film boiling about a dike
V. Numerical Simulation of Realistic Geothermal Fields
    A. Wairakei
    B. Heber
    C. East Mesa
    D. Salton Sea
    E. Cerro Prieto
    F. Baca
    G. Krafla
    H. Olkaria
    I. Serrazzano
    J. Broadlands (Ohaaki)
    K. USSR fields by Soviet Co-Author?
VI. References (as compiled)

Chapter 2.9
MANAGEMENT AND ECONOMICS OF GEOTHERMAL FIELDS

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Leningrad 199026 USSR

Chapter Outline
(5 Oct 90)

Suggested Responsible Co-Author

I. Introduction (SKS ?)
   A. Historical background
   B. The need for reservoir management
II. Management of Surface Equipment
   A. Routine maintenance
   B. Mitigation of scaling and corrosion
   C. Workovers
III. Management of Downhole Equipment
   A. Routine maintenance
   B. Prevention and mitigation of scaling and corrosion
   C. Workovers
IV. Management of the Reservoir
   A. Optimization of Production/Injection strategy
   B. Forecasting and minimizing make-up well requirement
   C. Minimizing operation cost
   D. Unusual management problems - case histories
V. Economic Analysis of Resource Supply
   A. Cash flow analysis
   B. Profitability criteria
   C. Sensitivity analysis
   D. Probabilistic approach
   E. Decision trees
VI. Concluding Remarks
VII. References (as compiled)

Chapter 2.10
POTENTIAL FOR MAGMATIC HEAT EXTRACTION

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Chapter Outline
(5 Oct 90)

Outline	Suggested Responsible Co-Author
I. Introduction	
A. Overall objective of chapter	(JD+VS)
B. Magma genesis and crustal intrusion	(VMS)
C. Worldwide potential of magma energy	(JCD)
II. Summary of Past Experiences	
A. The U.S. DOE Magma Energy Program	(JCD)
B. Magma definition and research in the USSR	(VMS)
C. Worldwide measurements and estimates of crustal magma characteristics including location and volume	(VMS)
III. Current Status of Development	
A. USA progress in the areas of: source location and definition; magma/materials compatibility; energy extraction; hazards	(JCD)
B. USSR characterization and development status	(VMS)
C. Worldwide characterization and development status	(JCD)
IV. Future Expectations and Research Needs	
A. The need for deep drilling	(JD+VS)
B. Future plans within the USA	(JCD)
C. Future plans within the USSR	(VMS)
D. Emerging programs in other countries (e.g.,Japan)	(JCD)
V. Discussion and Conclusions	(JD+VS)
VI. References	(as compiled)

Chapter 3.1
SPHERES OF UTILIZATION

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Chapter Outline (10 Oct 90)	Suggested Responsible Co-Author
I. Introduction	
A. Overall scope of chapter	(GH+BK)
various types of geothermal uses from past, present, and possibly future	
quantification of uses as possible	
B. History of topic	(GH+BK)
brief review of the literature	
C. Basic definitions	(GWH)
power; direct use; classes of non-power uses (e.g., agribusiness, light industrial; space heating; bathing; etc)	
D. General characteristics	(*)
condensed abstract (* second draft)	
II. Summary of Past Experience	
A. USA	(GWH)
B. USSR	(BMK)
C. World (Europe, FarEast(Japan, Indonesia, China))	(BMK)
(N., S., C. Americas, Philippines)	(GWH)
III. Current Status of Development	
A. USA	(GWH)
B. USSR	(BMK)
C. World (Europe, FarEast(Japan, Indonesia, China))	(BMK)
(N., S., C. Americas, Philippines)	(GWH)
IV. Future Expectations	
A. USA	(GWH)
B. USSR	(BMK)
C. World (Europe, FarEast(Japan, Indonesia, China))	(BMK)
(N., S., C. Americas, Philippines)	(GWH)
V. Discussion and Conclusions	(GH+BK)
VI. References	(as compiled)

Chapter 3.2
THERMODYNAMICS OF CONVERSION PROCESSES

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Chapter Outline (14 Oct 90)	Suggested Responsible Co-Author
I. Introduction (* = tbd)	(*)
A. Overall objectives	
B. Basic principles	
II. Applied First Law	(*)
A. Steam plant analysis	
B. Binary plant analysis	
C. Hybrid plant analysis	
III. Applied Second Law	(*)
A. Steam plant analysis	
B. Binary plant analysis	
C. Hybrid plant analysis	
IV. Property Values for Working Fluids	(*)
A. Steam properties	
B. Water/brine properties	
C. Binary working fluid properties	
V. Discussion and Conclusions	(*)
VI. References	(as compiled)

Chapter 3.3
ELECTRIC POWER PLANTS AND STEAM CYCLES

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Chapter Outline
(9 Oct 90)

Suggested Responsible Co-Author

I. Introduction (RGC ?)
   A. Objectives (on topics 1-5 below?)
      1. Brief history (* ??)
      2. Types of power plants (part of History ?)
         generic description of power plants
         detailed description of steam cycles
      3. Summary of past experiences (** ??)
      4. Current status of development (*** ??)
      5. Future expectations and needs (**** ??)
   B. History (* ??)
      1. Early power plants
         dry steam resources
            (e.g., Larderello, The Geysers)
         other
      2. Development of alternate cycles
         flashed steam; binary; total flow;
         geopressured; other
      3. Definitions
         thermodynamics; resources; other
II. Summary of Past Experience (** ??)
   A. USA
      1. Dry steam
         detailed description of cycle
            (process flow diagram; variations on cycle)
         dry steam power plants
            (The Geysers, HGPA (HI), other)
      2. Flashed steam
         detailed description of common cycles
            (process flow diagram; variations on cycle)
         flashed steam power plants
            (CA, NV, UT, other)
      3. General description of alternate cycles
         binary; geopressured; other
   B. USSR (VAV ?)
   C. World

III. Current Status of Development
    A. USA
        1. Dry steam cycles
        2. Flashed steam cycles
        3. other
    B. USSR
    C. World
IV. Future Expectations and Research Needs
    A. Dry steam cycles
        1. Handling corrosive steam
        2. Adapting power plants to declining resource pressure
        3. other
    B. Flashed steam cycles
        1. Adapting power plants to wide range of resource conditions
        2. Handling low temperature resources
        3. Total flow cycles
        4. other
V. Discussion and Conclusions
VI. References (as compiled)

Chapter 3.4
BINARY CONVERSION CYCLES

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Chapter Outline (8 Oct 90)	Suggested Responsible Co-Author
I. Introduction	
A. Scope to be covered and Objectives of chapter	(KEN)
B. Brief history of topic	(KEN)
C. Basic Definitions	(VAV)
D. General Discussion	(VAV)
II. Summary of Experience	
A. USA	(KEN)
B. USSR	(VAV)
C. World	(VAV)
III. Current Status and Development	
A. USA	(KEN)
B. USSR	(VAV)
C. World	(KEN)
IV. Future Expectations	(KEN)
Research Needs	(VAV)
V. Conclusions	(KN+VV)
VI. References	(as Compiled)

Chapter 3.5
ADVANCED CONVERSION CYCLES

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Chapter Outline
(30 Oct 90)

Outline	Suggested Responsible Co-Author
I. Introduction	(CJB ?)
A. Review of State-of-the-Art	
B. Logical efficiency (Second Law) limits	
II. Steam Systems (Direct and Flashed)	
A. Effective handling of noncondensables	
1. Reboiler cycles	
2. Other strategies	
B. Other advanced systems	
1. Combined steam and binary systems	
2. Other innovative systems	
III. Binary Systems	
A. Rankine cycle modifications	
1. Working fluid selection	
2. Countercurrent integral phase changes	
3. "Expansion through the vapor dome"	
4. Kalina System 12	
5. Other modifications	
B. Other innovative systems	
1. Original Kalina cycle	
2. Combined heat engine/heat pump systems	
3. Other systems	
IV. Discussion of Applicability and Conclusions	
V. References	(as compiled)

Chapter 3.6
BASIC DIRECT HEAT TECHNOLOGY

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USSR

Chapter Outline (9)ct 90)	Suggested Responsible Co-Author
I. Introduction	(GC ?)
A. Objective	
information on equipment and materials of construction to extract low-to-moderate temperature geothermal fluids from wells;	
transport and distribution of fluids and energy to point of use, and controls required	
brief discussion of corrosion and scaling affecting pumps, piping, heat exchangers, valves, control systems	
overall design philosophy with brief discussion of terminal equipment	
B. Brief history	
in USA	(GC)
in USSR	(NVO)
C. Basic definitions	(GC+NO)
D. General characteristics	(GC)
II. Summary of Past Experience	
A. USA	(GC)
1. Design philosophy	
2. Corrosion/Scaling	
water chemistry and problem species	
past problems	
solutions to problems	
3. Pumps	
well pumps (line-shaft turbine, submersible)	
surface pumps	
variable-speed drives	
4. Piping	
metallic (steel, ductile iron, copper)	
non-metallic (high & low density polyethylene, polybutylene, reinforced fiberglass, asbestos cement, PVC and CPVC)	
insulation (pre- and post-insulated)	
installation	

5. Heat Exchangers
   tube and shell
   plate and frame

      (description, materials, heat transfer coeff.)
   brazed plate
      (description, materials, potential problems)
   downhole heat exchangers
      (description, advantages, disadvantages, design)
6. Absorption Cooling
7. Controls and Valves
   basic control schemes
   valves
      (types, materials)

B. USSR (similar section) (NVO)

III. Current Status of Development
   A. USA (GC)
   B. USSR (NVO)
   C. World (GC+NVO)

IV. Future Expectations and Research Needs
   A. USA (GC)
   B. USSR (NVO)

V. Discussion and Conclusions
   A. Comparison of USA and USSR equipment, methods, materials, and design
   B. Discussion of advantages and disadvantages of these relative to each country
   C. Discussion on differences in design and equipment utilization philosophies

VI. References (as compiled)

Chapter 3.7
MUNICIPAL HEAT SUPPLY SYSTEMS

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USSR

Chapter Outline (9 Oct 90)	Suggested Responsible Co-Author
I. Introduction	
A. Objective	(GMG)
B. USA history	(KR)
C. USSR history	(GMG)
D. Definitions	(KR+GMG)
II. Summary of Past Experience	
A. USA	(KR)
1. Typical geothermal system design	
open systems; closed systems; basic subsections	
2. Production	
resources used (wells); pumps; drives	
3. Central plants	
major components	
(heat exchangers, pumps, controls, etc)	
metering	
4. Distribution	
piping; temperature control; valves	
5. Customer connections	
branch lines; metering; ΔT temperature control	
6. Disposal	
injection; surface	
7. Economics	
capital costs; operating costs; rates	
B. USSR (similar section)	(GMG)
III. Current Status of Development	
A. USA	(KR)
Extent of GHD development	
locations; system descriptions	
B. USSR	(GMG)
IV. Future Prospects and Research Needs	
A. USA	(KR)
1. Regulations	
2. Government support	
3. Computation of fuel costs	
4. Environmental issues	
5. Research needs	
B. USSR	(GMG)
V. References	(as compiled)

Chapter 3.8
INDUSTRIAL HEAT AND MINERAL EXTRACTION

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Chapter Outline (9 Oct 90)	Suggested Responsible Co-Author

I. Introduction (DTT ?)
- A. Objectives
  1. Comprehensive listing of historic, current, and future applications of geothermal resources (heat, fluid, dissolved solids).
  2. Analysis of resource characteristics, economic, logistic, and application-related factors affecting pattern of direct use of geothermal energy, past and future
- B. Historical perspective
  1. Where and how industrial applications began
  2. Ties to industrial societies and nations
  3. Examples of prehistoric examples (e.g., fowl scalding, pitch removal, sulfur collection, bread baking, vegetable dye preparation)
  4. Definitions
     - industrial application
     - process heat
     - mineral processing (extraction, leaching, etc)
  5. Resource characteristics
     - temperature (e.g., Lindal diagram)
     - chemical composition (TDS, Ph, dissolved species)
     - depth to resource
     - well field productivity
     - well field configuration (areal extent)
  6. Application characteristics
     - distance to markets (sales, trades)
     - distance to population centers (labor, management)
     - timeframe of production
     - appropriate alternatives
     - energy conversion technology (hardware)

II. Previous Applications
- A. USA (DDT ?)
  1. Grain drying - South Dakota
  2. Ethanol production - Nevada, Idaho
  3. Mineral processing - Texas
- B. USSR (FGS ?)
- C. Worldwide
  1. Borate salts to glaze ceramics

III. Current Status of Development

A. USA

1. Dehydration - onion drying plant, Nevada
2. Refrigeration - mushroom growing, Oregon
3. Mineral processing - cyanide leaching of precious metals, Nevada
4. Laundry - Wyoming, Nevada
5. Highway deicing - Oregon

B. USSR

C. Worldwide

1. Process heat in manufacturing
   textiles - China; dyeing - China
   tanning leather - China, Turkey
   glue - China, Turkey; pulp and paper - New Zealand
   wood veneer - New Zealand; rubber - Turkey
2. Dehydration
   seaweed - Iceland; diatomaceous earth - Iceland
   timber drying - New Zealand; alfalfa - New Zealand
   agricultural products - Kenya, Hungary, Yugoslavia
3. Mineral processing and extraction
   chemicals - China; salt production - Iceland, Japan
   borates - Italy; boric acid - Italy
   sulfuric acid - Japan; elemental sulfur - Japan
   (here ?) rare earth extraction - USSR

IV. Potential Applications and Research Needs

A. Assessment techniques: economic models

B. Economic triggers, energy shortages, development incentives

C. Future raw material requirements (minerals, water)

D. Energy cascading from existing geothermal power plant discharge

V. Discussion and Conclusions

VI. References (as compiled)

Chapter 3.9
AGRICULTURAL AND AQUACULTURAL HEAT SUPPLY

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Chapter Outline
(9 Oct 90)

Suggested Responsible Co-Author

I. Introduction (RS ?)
   A. Topics:
      greenhouses, aquaculture, other
   B. Why greenhouses and aquaculture systems are favorable applications for geothermal energy
   C. Definition of low-enthalpy resources
   D. Applicable temperature ranges
II. Greenhouses
   A. History of geothermal greenhouse heating
   B. Technical design considerations
      1. greenhouses
         construction and materials
         temperature and humidity controls
         space utilization efficiency
         irrigation water conditioning
      2. geothermal heating systems
         heat loss principles
         air and soil heating systems
         energy conservation features
      3. economic considerations
         capital and operating costs
III. Summary of Past Experience
   A. USA (RS ?)
      1. History of USA geothermal greenhouse projects
      2. Growth trends of industry (if available)
      3. Successful projects
      4. Project failures with reasons for failure
   B. USSR (IMD ?)
      1. History of USA geothermal greenhouse projects
      2. Growth trends of industry (if available)
      3. Successful projects
      4. Project failures with reasons for failure
   C. World

IV. Current Status of Geothermal Greenhouse Development
   A. USA
      1. Size of geothermal greenhouse industry
      2. Annual geothermal energy utilized
      3. Number and types of business, locations
      4. Typical crops and products
      5. Typical geothermal resource parameters
      6. Discussion of selected greenhouse businesses
      7. Research and development programs
      8. Government incentives
   B. USSR
      1. Size of geothermal greenhouse industry
      2. Annual geothermal energy utilized
      3. Number and types of business, locations
      4. Typical crops and products
      5. Locations
      6. Typical geothermal resource parameters
      7. Discussion of selected greenhouses
      8. Research and development programs
      9. Government incentives
   C. World
      same topics as above for other countries
        e.g., Japan, China, Europe, New Zealand
V. Aquaculture
   A. History of geothermal aquaculture production
   B. Technical design considerations
      1. Aquaculture systems
         intensive and extensive systems
         culture species
         water quality requirements
      2. Geothermal heating systems
         heat loss principles
         direct and indirect systems
         cascaded systems
         energy and water conservation features
         temperature controls
      3. Summary of past experience
         USA
           history of USA geothermal aquaculture projects
           growth trends of industry (if available)
           successful projects
           project failures with reasons for failure
         USSR
           history of USA geothermal aquaculture projects
           growth trends of industry (if available)
           successful projects
           project failures with reasons for failure
         World

VI. Current Status of Geothermal Aquaculture Development

A. USA

1. Size of geothermal aquaculture industry
2. Annual geothermal energy utilized
3. Number and types of businesses
4. Cultured species and production
5. Locations
6. Typical geothermal resource parameters
7. Discussion of selected aquaculture installations
8. Research and development programs

B. USSR

1. Size of geothermal aquaculture industry
2. Annual geothermal energy utilized
3. Number and types of aquaculture installations
4. Cultured species and production
5. Locations
6. Typical geothermal resource parameters
7. Discussion of selected aquaculture installations
8. Research and development programs

C. World

same topics as above for other countries
e.g., Japan, China, Europe, New Zealand

VII. Other Agricultural Applications

Short discussion of USA, USSR, and worldwide projects

VIII. Future Expectations and Research Needs

A. Industry growth projections

B. Industry trends

C. Factors affecting growth

economics
(fuel/operating cost; capital cost of geothermal heat; government incentives)
environmental

D. Research needs

IX. Discussion and Conclusions

Summary

X. References (as compiled)

Chapter 3.10
THERMAL WATER BALNEOLOGY

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Chapter Outline
(9 Oct 90)

Outline	Suggested Responsible Co-Author
I. Overall Objectives of Chapter	
A. Medical developments	(AI)
B. Engineering equipment and methods of using geothermal fluids	(JWL)
C. Brief history related to early use by Romans, Ottomans, Central Europeans, Japanese, etc	(AI+JWL)
D. Basic definitions	(AI+JWL)
II. Summary of Past Experience	
A. USA	(JWL)
B. USSR	(AI)
C. World (e.g., Japan, Czechoslovakia, others)	(JWL)
III. Current Status of Development	
A. USA, including engineering	(JWL)
B. USSR	(AI)
C. World	(AI+JWL)
IV. Future Expectations and Research Needs	
A. Medical aspects	(AI)
B. Engineering aspects	(JWL)
V. Discussion	(JWL+AI)
A. Contrast of difference in balneology and health spa operations and use between USA (relaxation) and Europe (medical healing)	
B. Trends in both areas	
VI. References	(as compiled)

Chapter 3.11
ENVIRONMENTAL ASPECTS OF GEOTHERMAL POWER ENGINEERING

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Chapter Outline
(9 Oct 90)

Suggested Responsible Co-Author

I. Introduction (DLC ?)
   A. Objectives
      1. Identify and characterize the environmental impacts associated with geothermal exploration and development activities
      2. Discuss methods currently used for mitigating unavoidable environmental impacts
      3. Identify new or unforseen potential impacts from long-term development of geothermal resources
      4. Forecast future environmental issues associated with geothermal energy exploration and development
   B. Historical Perspective of the Environmental Aspects of Geothermal Resource Development
      1. Environmental impacts of early geothermal exploration and development operations
      2. Evolution of regulatory restrictions and control
      3. Public involvement in resource development
      4. Mitigated geothermal energy projects
   C. Basic Definitions
      1. Significant legislation applicable to the Environmental aspects of geothermal development
         National Environmental Policy Act
         Clean Air and Clean Water Acts
         National Historic Preservation Act
         Endangered Species Act
         Geothermal Steam Act
         State and local legislation
      2. Environmental review and impact assessment process
         Air quality impacts
         Water quality/hydrologic resource impacts
         Geologic impacts
         Cultural and biologic impacts
         Socioeconomic impacts

II. Environmental Impacts from Historic Geothermal Energy Development
    A. USA
        1. Environmental conflicts in sensitive areas
            Geysers experience; Sierras; Hawaii
        2. Environmental considerations in other areas
            Imperial Valley; Coso Hot Springs; Nevada
    B. USSR (BI)
    C. World
        (e.g., New Zealand; Iceland; Japan; Philippines)
III. Environmental Aspects of Current Geothermal Development
    A. USA
        1. Stricter pollution control requirements
        2. Health and safety issues
        3. Competing uses of resources
        4. Aesthetic impacts (noise; visual; odors; etc)
        5. Cumulative impact considerations
    B. Hydrothermal convection systems (BI)
    C. World
IV. Future Environmental Issues and Research Needs
    A. Air pollution abatement requirements
    B. Water resource availability and alternate cooling systems
    C. Project closure and post-closure requirements
    D. Competing uses of resources
    E. Cumulative impact restrictions
V. Discussion and Conclusions
VI. References (as compiled)

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Soviet-American Monograph on Geothermal Energy

To: Patrick Muffler, Hugh Murphy, John Lund
All American Co-Authors

Subject: News Memo No. 2

Date: 18 October 1990

This is the second general news memo on the status of the Soviet-American Monograph on Geothermal Energy, Task Project 4 of the Stanford University - Leningrad Mining Institute Geothermal Agreement. Prof. Yuri D. Dyadkin, Co-Editor of the Monograph, visited Stanford from 13 Sept to 11 Oct 1990 and much progress was achieved on getting the Preparation of the Monograph underway. Because of a difficult itinerary, meetings were held individually with each of the US volume Co-Editors and consensus became a cumulative process. Pat Muffler was first (before leaving for an extended trip), but the final decisions reflect much of his thinking.

In view of the lengthy (and sometimes erratic) times for exchange of correspondence through the Soviet (and American) postal services, it was deemed desirable for Dr. Dyadkin to hand carry as many of the initial drafts of the Suggested Chapter Outlines with him on return to Leningrad. Each of the US responsible Co-Authors has been contacted by the Volume Editors and the Outlines have been arriving by Fax in good order. Dr. Dyadkin left with 18 of the 26 Chapter Outlines and 4 more have been sent on. The remaining 4 will be forwarded as soon as they are received.

Several other activities under the SU-LMI Agreement bear on Task 4. One key one is the schedule of meetings to complete the Monograph. The first may be a series of formal invitations to the US Volume Co-Editors for a meeting in Leningrad, each invited by the respective Soviet Co-Editor's institution. If this works out, it will be the first opportunity to resolve the difficult problems of correspondence, translations, publication procedures, etc, that require having completed first drafts of all of the chapters. The Co-Editors have set April, 1991 as a necessary date for completion of the First Draft of the 26 Chapters of the Monograph. The philosophy is to allow each pair of responsible Co-Authors to work out the technical details of the Chapter by themselves. The general feeling is to have a sort of "Annual Reviews" type of chapter with extensive coverage of the US, Soviet, and world literature, and without attempting to make an exhaustive treatise of geothermal energy. Thus, editing will not really start until the Co-Authors have had a chance to work things out individually and written the first draft.

The second major date is the Spring of 1992 when the newly formed Soviet Geothermal Association hopes to hold its First International Symposium, planned for the Crimea region near the Black Sea. An initial flyer on the SGA (enclosed) was prepared by Dr. Dyadkin during his visit. The hopes are to hold a Co-Authors' Get-Together at this meeting to finalize any still-existing problems. More on this later. The current schedule is as follows:

Nov 90 Initial contact from Soviet Co-Authors in response to Suggested Chapter Outlines
Apr 91 First Draft of Chapters due to Volume Editors
Jun 91 Editors meeting to resolve issues and plan publication
Jul 91 Comments back to Co-Authors
Jan 92 Final Drafts to Volume Editors
Mar 92 Completion of Equivalent Translations
Apr 92 Editors/Authors meeting to complete Manuscripts
Aug 92 Manuscripts to Publishers

To speed up the efficient initiation of the Preparation of the chapters, I plan to prepare a uniform set of the Chapter Outlines of the Monograph and forward these to the Soviet Editors as they are revised. Thus, the preparation of Outlines to ensure uniform coverage will be an ongoing process at least until the end of this year. I am enclosing copies of the first two Outlines in this format as random examples. Please continue to develop the Outlines until (and After) you hear from your Soviet Co-Author. Please send me (and Volume Editor) copies of your revised Outlines and I will forward them to LMI and distribute copies to all of our Co-Authors, so that everyone will be familiar with the Scope of the Monograph. I will distribute a third News Memo with the set of Outlines.

Best Wishes,
Paul Kruger

Chapter 1.1
NATURE OF GEOTHERMAL ENERGY

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21st Liniya No.2
Leningrad 199026 USSR

Chapter Outline
(19 Sep 90)

Suggested Responsible Co-Author

I. Definition of geothermal energy (WAD ?)
  A. Sources of geothermal energy
  B. Distribution and movement of geothermal energy within the Earth

II. Geothermal energy in the upper crust
  A. Amount of geothermal energy within the upper few kilometers
  B. Background geothermal flux across the Earth's surface
  C. Regional geothermal regimes

III. Types of geothermal anomalies in the upper crust
  A. Magma bodies
  B. Hydrothermal convection systems
  C. Hot dry rock
  D. Interrelations among magma, hydrothermal convection, and hot dry rock

IV. Geothermal energy and the environment
  A. Types of environmental impacts associated with geothermal developments
  B. Means of mitigating environmental impacts
  C. Comparisons with environmental impacts associated with hydrocarbons and other fossil fuels

V. Speculations on the role of geothermal energy during the 21st Century

Chapter 2.10
POTENTIAL FOR MAGMATIC HEAT EXTRACTION

American CoAuthor: James C. Dunn
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Soviet CoAuthor: Victor M. Sugrobov
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Academy of Sciences USSR
Petropavlovsk, Kamchatka
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Fax: tbd

Chapter Outline
(5 Oct 90)

	Suggested Responsible Co-Author
I. Introduction	
A. Overall objective of chapter	(JD+VS)
B. Magma genesis and crustal intrusion	(VMS)
C. Worldwide potential of magma energy	(JCD)
II. Summary of Past Experiences	
A. The U.S. DOE Magma Energy Program	(JCD)
B. Magma definition and research in the USSR	(VMS)
C. Worldwide measurements and estimates of crustal magma characteristics including location and volume	(VMS)
III. Current Status of Development	
A. U.S. progress in the areas of: source location and definition; magma/materials compatibility; energy extraction; hazards	(JCD)
B. USSR characterization and development status	(VMS)
C. Worldwide characterization and development status	(JCD)
IV. Future Expectations and Research Needs	
A. The need for deep drilling	(JD+VS)
B. Future plans within the USA	(JCD)
C. Future plans within the USSR	(VMS)
D. Emerging programs in other countries (Japan)	(JCD)
V. Discussion and Conclusions	(JD+VS)
VI. References (as compiled)	

not distributed

Chapter 1.4
RATION GEOSCIENCES

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peta Way Ste.C
ke City, UT 84108

r I. Kononov | Tel: tbd
cal Institute AS | Fax: tbd
USSR

Mike —
how about a revision to send to LMI?
Paul

apter Outline
(21 Sep 90)

Suggested Responsible Co-Author

I. Introduction (PMW ?)
   A. Objective of Chapter
      To review application of geological, geochemical, and, geophysical techniques to regional exploration for geothermal resources
   B. History of geothermal exploratio
      Brief summary of early development, techniques used, philosophy
   C. Summary
      Summary of exploration methods and exploration strategies
II. Review of Regional Exploration Techniques
   A. Classification of techniques and comparison of techniques used to those used for mining and petroleum exploration
   B. Geological techniques of geologic mapping; study of drill samples; age dating; structural studies; geologic interpretation
   C. Geochemical techniques of chemistry of thermal fluids; major,minor, and trace elements in rocks; hydrothermal alteration; isotope studies; fluid inclusions
   D. Geophysical techniques of thermal, electrical, gravity, magnetic, seismic, and seismological methods, and remote sensing
III. Regional Exploration Strategies
   A. Summary of application of geosciences, exploration strategies
   B. Regional area selection with characteristics of geothermal environments (arid, wet, crystalline-rock, volcanic-rock, sedimentary-rock
   C. Regional exploration, exploration process, regional exploration strategies
IV. Exploration Case Studies (also for USSR ?)
   A. Geothermal provinces in the USA; summary of regional exploration in the USA
   B. Exploration of the Basin and Range, western USA
   C. Exploration of the Imperial Valley, southwest USA
V. Future Expectations and Research Needs
   A. Future of geothermal exploration in the USA (PMW?)
   B. (same for USSR ?) (VIK?)
   C. Research needed to improve exploration techniques
VI. Discussion and Conclusions
VII. References (as compiled)

SOVIET GEOTHERMAL ASSOCIATION (USSR SGA)

▪ The Soviet Geothermal Association is an independent engineering society, acting as a part of the International Geothermal Association (IGA).

▪ SGA is an association of USSR and foreign Institutions, independent groups, and individuals, who are interesting in research on all aspects of GEOTHERMICS, development of GEOTHERMAL TECHNOLOGY, improving its ECONOMIC and ENVIRONMENTAL efficiency, expanding the realm of geothermal RESOURCES, spheres and scope of their APPLICATION in the USSR and DISTRIBUTION of Soviet advanced experience to other Countries;

▪ SGA primary OBJECTIVES are:

- to improve INTERACTION, mutual CONTACTS and to joint FORCES of all geothermal Institutions, Groups and Individuals by EXPANDING exchanges of INFORMATION about their GEOTHERMAL ACTIVITIES;
- to SUPPORT actual geothermal PROJECTS ;
- to FOUND joint VENTURES for EXPERIMENTAL and COMMERCIAL geothermal PROJECTS;
- to DEVELOP RECOMMENDATIONS on geothermal energy in INDUSTRIAL, AGRICULTURAL, or any other commercial APPLICATIONS.

▪ SGA MEMBERS can be research, education, and design Institutes, industrial, agricultural, business, commercial and non-commercial corporations, enterprises, companies, cooperatives, societies, theirs divisions and separate groups and individual scientists, experts, engineers, students and other individuals both from the USSR or foreigners;

▪ SGA MEMBERSHIP gives You:

- a free copy of the SGA quarterly GEOTHERMAL BULLETIN;
- a free copy of the SGA annual GEOTHERMAL TRANSACTIONS;
- free participation in SGA annual CONFERENCE or SYMPOSIUM;
- free short SGA REVIEWS on any geothermal problem and SGA LISTS on references or patents on any required specific topic from the SGA GEOTHERMAL COMPUTER BANK OF INFORMATION;
- opportunity to ANNOUNCE, PUBLISH, and DISTRIBUTE among geothermal people Your SCIENTIFIC and COMMERCIAL information by printing this materials in SGA publications;

▪ SGA Membership CHARGES :

• for FOUNDERS	15,000 Rubles	
• for Co-FOUNDERS	5,000	
• for INSTITUTIONAL members	2,000	Annually
• for CORPORATION members	500	Annually
• for INDIVIDUALS	5	Annually
• Students	1	Annually
• Foreign members	$10	Annually

■ The BYLAWS of SGA were confirmed at the FOUNDING MEETING on 24 February 1990 in LENINGRAD, USSR.

■ SGA RESIDENCE is in Research Laboratory of Mining Thermophysics (PNIL GTPh) of the Leningrad Mining Institute (LMI)

MAILING ADDRESS: LMI-PNIL GTPh-SGA
2, 21st Linia
LENINGRAD, 199026 USSR

LMI TELEX: 121 494 LGIP SU
SGA Tel: 355-0113, 355-0112, 218-8652

■ The President of SGA is Prof. Yuri D. Dyadkin,
Head of Ore Mining and Mining Thermophysics Dept.,
Leningrad Mining Institute, Leningrad.
Supervisor of PNIL GTPh LMI.

■ SGA CO-CHAIRMEN:

Prof. Emil I. Boguslavsky
Leningrad Mining Inst., Leningrad

Prof. Haindrik S. Vartanyan
All-Union Inst. of Hydrogeology and Engineering Geology, Moscow

Dr. Gaidar M. Gaidarov
All-Union Research and Design Inst. on Geothermics, Makhachkala

Dr. Vladimir A. Khityev
State Research and Design Inst. GIPRONIKEL, Leningrad

Foreign SGA Co-CHAIRMAN:

Prof. Paul Kruger
Stanford University, Stanford

IGA-SGA Coordinator:

Prof. Guram I. Buatchidze
Sector Hydrogeology, A.S. of GSSR, Tbilisi

US Academy of Sciences Coordinator:

Prof. Vladimir I. Kononov
US-AS Council on Geothermics, Moscow

Ukraine Ac. Sci. Coordinator:

Academician Anatoli A. Dolinsky
Inst. Tech. Thermophysics, Kiev

SGA Secretaries;

Dr. Albert G. Vasiliev - PNIL GTPh LMI, Leningrad
Dr. Anna B. Vainblat - PNIL GTPh LMI, Leningrad

■ On 1 Sept 1990, membership in the SGA included 4 Founders, 7 Co-Founders, and 10 Institutional members from Leningrad, Moscow, Kiev, Tbilisi, Makhachkala, Yaroslavl, Tirniaus, Vilnus, Simpheropol, and Lyvov.

■ SGA is now open for Membership.
You, Your Group, Your Institute are welcome to join the Soviet Geothermal Association !

Chapter 1.~~4~~ 3

EXPLORATION GEOSCIENCES

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Fax: tbd
Telex: tbd

Chapter Outline
(21 Sep 90)

Suggested Responsible Co-Author

right — I. Introduction (PMW ?)
131 A. Objective of Chapter A1 A3
To review application of geological, geochemical, and, geophysical techniques to regional exploration for geothermal resources
B. History of geothermal exploration
Brief summary of early development, techniques used, philosophy
C. Summary
Summary of exploration methods and exploration strategies

M. Wright 1.32. Review of Regional Exploration Techniques
A. Classification of techniques ~~and comparison of techniques used to those used for mining and petroleum exploration~~
Kononov B. Geological techniques of geologic mapping; study of drill samples; age dating; structural studies; geologic interpretation
Kononov D. Geochemical techniques of chemistry of thermal fluids; major, minor, ~~and trace~~ elements in rocks; hydrothermal alteration; isotope studies; fluid inclusions
Zubin B. Geophysical techniques of thermal, electrical, gravity, magnetic, seismic, and seismological methods, and remote sensing

right — 133. Regional Exploration Strategies
A. Summary of application of geosciences, exploration strategies
B. Regional area selection with characteristics of geothermal environments (arid, wet, crystalline-rock, volcanic-rock, sedimentary-rock
C. Regional exploration, exploration process, regional exploration strategies

IV. Exploration Case Studies (also for USSR ?)
A. Geothermal provinces in the USA; summary of regional exploration in the USA
B. Exploration of the Basin and Range, western USA
C. Exploration of the Imperial Valley, southwest USA

V. Future Expectations and Research Needs
A. Future of geothermal exploration in the USA (PMW?)
B. (same for USSR ?) (VIK?)
C. Research needed to improve exploration techniques

(Possibly...)

~~VI~~. Discussion and Conclusions

VII. References (as compiled)

Wright

TELEFAX COVER SHEET

TO: Phillip M. Wright
UURI
Salt Lake City, UT
Fax: 8-588-3453

From: Patrick Muffler
U.S. Geological Survey
Menlo Park, CA
Fax: FTS 459--5110
Tel: FTS 459--5239

14 September 1990, 15:49 PDT
Number of pages including this one: 2

I met today with Yuri Dyadkin (just arrived from the Soviet Union) and Paul Kruger concerning the joint Soviet-American Monograph on Geothermal Energy. Dyadkin brought a list of the counterpart Soviet authors. For Volume 1 they are:

1.1 Nature of Geothermal Energy
USSR: A.A. Smislov (Leningrad Mining Institute, Academy of Sciences)
USA: Wendell A. Duffield (USGS)

1.2 Heat Flow Distribution and Geothermal Anomalies
USSR: Ya. B. Smirnov (Geological Institute, Academy of Sciences)
A. Smislov (Leningrad Mining Institute, Academy of Sciences)
USA: David D. Blackwell (SMU)

1.3 Resource Base and Resource by Type
USSR: A.A. Shpak (All-Union Research Institute of Hydrogeology and Engineering Geology)
A. Vainblat (Leningrad Mining Institute)
USA: L.J. Patrick Muffler (USGS)

1.4 Exploration Geosciences (Geology, Geophysics, Geochemistry)
USSR: V. Kononov (Geological Institute, Academy of Sciences)
S. Kasparov (Institute of Geothermal Problems, Makhachkala)
V. Baibakov (Institute of Geology and Geochemistry of Mineral Fuels, Lvov)
USA: Phillip M. Wright (UURI)

1.5 Prospect Evaluation
USSR: E. Boguslavski (Leningrad Mining Institute)
USA: Norman E. Goldstein (LBL)

As first step in establishing communication and cooperation between respective co-authors, Paul, Yuri, and I are asking you to crank out a rough outline of what you think should be in your chapter, basing it in general upon the generic outline suggested by Paul in his 30 March 1990 memorandum to all American authors, but modifying the generic outline as required by your particular topic. Please make a guess as to the overall length (in double-spaced typewritten pages) and the length of major component sections. Dyadkin will take these outlines with him when he returns to Moscow on 11 October 1990 and distribute them to the respective co-authors and to V. Kononov (my counterpart editor for volume 1. If we do it this way rather than by mail, we save as much as two months time. Mail to and from the USSR is incredibly slow.

Since I shall be in the field at least until 01 October, please fax your outline and page estimates directly to Kruger at (415) 725-8662.

During the next few weeks, Kruger and Dyadkin will be making plans for completion of the monograph, including a schedule of meetings and major milestones. During this time, Kruger will determine the address of your co-author and will supply it to you.

After a long period of non-communication on this monograph, I suspect this request sounds a little abrupt and "out of the blue". Please understand that Dyadkin arrived only yesterday (after a week's delay owing to frustrating encounters with US bureaucracy in his attempts to get the required visa), I leave for the field on Monday 17 September, and we really want to take full advantage of Yuri's presence here and the opportunity to short-cut the constipated US/Soviet mail communication. Thanks very much for your quick response to Kruger.

GEOTHERMICS

INTERNATIONAL JOURNAL OF GEOTHERMAL RESEARCH AND ITS APPLICATIONS

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Salt Lake City, UT
Fax: 8-588-3453

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U.S. Geological Survey
Menlo Park, CA
Fax: FTS 459--5110
Tel: FTS 459--5239

15 September 1990, 15:24 PDT
Number of pages including this one: 1

I have just received from Pisa a manuscript by R. Balia, M. Ciminale, M. Loddo, D. Patella, G. Pecorini, and A. Tramacere entitled "A new geophysical contribution to the study of the Campidano geothermal area (Sardinia, Italy). It deals with geology, gravity, dipole-dipole resistivity, and magnetics - right up your alley! Would you be willing to arrange for a review of this manuscript? It also has been sent to Axel Björnsson.

If you can arrange for the review, please call my secretary, Mary Ann Mikus, at FTS 459-5226, and she will send the manscript and the review sheet to you.

I leave for the field Monday monring and will be gone until at least 01 October.

Patrick

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... Headington Hill Hall, Oxford OX3 0BW, England / Fairview Park, Elmsford, New York 10523, USA

DOE F 1325.8
(8-89)

10157a
→ Marshall

United States Government Department of Energy

memorandum

DATE: September 7, 1990 (REVISION to August 2, 1990 memo)

REPLY TO ATTN OF: CE-20

SUBJECT: TRIP REPORT: US-USSR Energy Bilateral Fact Finding Visit to USSR July 14-26, 1990

TO: J. Michael Davis, CE-1
B. Reid Detchon, CE-2
Deputy Assistant Secretaries
Gary Moore, CE-70

Purpose

The subject trip was made as a follow-up to a USSR delegation visit to DOE in January 1990, at which time a number of proposals were offered for U.S.-USSR collaboration on non-nuclear energy technology. The purpose of the trip was fact finding relative to USSR interests and capabilities. There was no expectation that the trip would result in a signed agreement for collaboration, but only a better defined direction for future discussions.

U.S. Delegation

The U.S. participants who represented DOE were from, IE, FE, CE, and EI. In addition, there were representatives from the Commerce and State Departments, as well as two professional interpreters. (See attached list)

USSR Hosts

All arrangements for the visit were made by the USSR Bureau of Fuels and Energy Complex; but there were many other participants including members of the various subordinate Ministries, representative of regional, political, and power authorities, members of the Academy of Science, and representatives of numerous Institutes (associated with both the Ministries and with the Academy).

Agenda

A very busy meeting and travel agenda had been prepared for us, with no flexibility for the first seven days. Following delegation and plenary meetings with the Soviets in Moscow on July 15 and 16, the delegation divided into two groups - Group I traveling to Novasibersk and Kiev and Group II traveling to Urengoi and Yamburg. (I lead Group I) The Group I travels included visits to the Institutes at Akademgorodok, to a coke production facility in Zerinsk, to power plants in Novosibersk and Kiev and to the Paton Institute in Kiev. Group I and Group II -- these groups reunited in Moscow on July 20 for more meetings with Institutes with the Ministry of Electrification, and with the Academy of Science. Summary meetings were held on July 23 with Mssrs. Ryaboff and Margolov, our hosts. July 24 and 25 were available for follow-up meetings. During that time, I was able to meet with the Ministry of Metallurgy, with the Krzhizhanovsky Institute, and with Mr. Vasiliev on matters of specific interests. These were productive meetings. An attempt to reach the Ministry of Electrotechnical Industry on lighting technology was not successful.

Assessment of Soviet Technology

Good scientific work is being done at the various Institutes which were visited. Some are clearly stronger than others. I was most impressed with the Paton Institute and the Institute for High Temperature. I had the impression that the experimental equipment and instrumentation are in some cases out of date. I saw no real "zingers" with respect to new technology. I saw a few things that may deserve further examination - catalysis at low temperature involving no platinum group metals - advanced heat pumps for industrial application - a two axis solar concentrator with stirling engine converter operating at 16% overall. Competition between institutes and between individuals is very strong and perhaps disruptive. Many of the examples of accomplishments were obviously quite old and may have been presented only out of respect to the stature of their proponents.

Doing Business In the USSR

American companies who want to take part in a growing Soviet economy must find a way to get their money out. Barter agreements have been the answer in many cases. Pepsi for Vodka is a well known example of a successful barter agreement but others are developing. We spoke to the manager of a Polaroid Joint venture, which plans to generate sufficient hard currency through the sale of camera components into the west to satisfy its obligation to the parent company.

Opportunities For Collaboration

- There is recognition in the USSR of the need to improve energy efficiency to meet growing demand and to stabilize emissions. The time is here to upgrade industry and power generating facilities with the best available technology to meet the protected need. This could be a big opportunity for U.S. firms willing to do business in the USSR.

- CNG fueled vehicles are being introduced in urban areas. Two thousands are now in place. This number is expected to reach 1.5 million vehicles within several years. This could be an opportunity for data exchange.

- The USSR has a very large geothermal resource. They recognize a need for improved prospecting means, and would like to collaborate with a U.S company or University to do geothermal mapping.

- They talked of converting existing gas turbines to "ISTIG's" (intercooled steam injected gas turbines) to increase gas fired capacity. U.S. manufactures could play a role in this area.

- They are nearing operation on a small solar thermal generator - 2 axis concentrators with receiver at 600°C, stirling engine conversion at 16%.

- They claim catalytic reactions at low temperature with no platinum group materials - research work continues at the Institute of High Temps and at Akademgorodok.

- Data was provided on an industrial heat pump system under development at the Institute of High Temperature.

- Information was collected from several sources on advanced metallurgical coke-making. Several precesses are under development which may be of interest to the U.S. ferrous metals industry.

- A modular housing unit was presented by the Soviets at a recent RETSIE conference. Some interest was expressed by U.S. participants at that meeting. The Soviets would like to find a U.S. partner to manufacture and promote this product.

- Other possible joint ventures were suggested which would involve manufacturing and distribution in the USSR. They are:

  - Advanced lamp products
  - Small boilers for replacement (300,000 needed)
  - Heat pumps for district heating
  - Insulated pipe for district heating

General Conditions

The Soviet people were very open, friendly, and helpful with all members of our delegation. They are interested in Americans and in our way of life. Many Soviets live in poor conditions and now seem hopeful that things will improve. Only the very elite enjoy the luxuries that are commonly available to average U.S. citizens.

Record of Meetings

On July 24, 1990, the U.S. delegation leader, Mr. Thad Grundy, met with the Soviet delegation leader, Mr. Grant Margulov, at which time the record of the meeting was approved and signed. A copy of that record is attached.

Chronicle of Events

A draft chronicle of events is attached.

Alan J. Streb
Deputy Assistant Secretary
for Industrial Technologies

Attachment

cc: Gene De La Torre, IE-12

UNCLASSIFIED

ASKEW/IE:GDELATORRE
06/06/90:586-6121
OUR/SOV:AVERSHBOW

USDOE/IE:HJAFFE
EUR/SOV:SSMITH
DOC:JBROUGHER
OSTP:JONEIL(INFO)

OES/SCT:MPROCHNIK
OES/SCT:CCAMPBELL
EB/ERF/EPC:SGALLOGLY
EUR/SOV/ECON:JHERBST

PRIORITY MOSCOW

N/A

TRGY, ENRG, QTRA, UR, US

VISA INFORMATION SUPPORTING US FACT-FINDING VISIT TO USSR ON NON-NUCLEAR ENERGY POLICY AND ENERGY TECHNOLOGY PROGRAM

OFFICIAL BUSINESS	D.O.B.	PASSPORT NO.	EXPIRATION
THAD GRUNDY, JR. DEPUTY ASSISTANT SECRETARY FOR INTERNATIONAL AFFAIRS (IE)	3/6/90	800435770	3/95
GENE DE LA TORRE OFFICE FOR INTERNATIONAL RESEARCH AND DEVELOPMENT POLICY AND EXECUTIVE SECRETARY FOR THE VISIT, DOE/IE	1/31/38	800273012	3/93
DAVID PUMPHREY DIRECTOR, ENERGY ASSESSMENTS DIVISION	4/15/49	800161509	1/92

DOE/IE

LANA EKIMOFF ENERGY ASSESSMENTS DIVISION, DOE/IE	12/27/44	800107480	5/91
GEORGE RUDINS PRINCIPAL DEPUTY ASSISTANT SECRETARY FOR RESEARCH AND DEVELOPMENT, OFFICE OF COAL TECHNOLOGY	12/1/43	800488695	4/95
GEORGE STOUSUR PROGRAM MANAGER FOR ENHANCED OIL RECOVERY (FE)	7/9/37	800352228	2/94
THOMAS BECHTEL DIRECTOR, MORGANTOWN ENERGY TECHNOLOGY CENTER (METC)	6/5/36	800396699	7/94
HUGH GUTHRIE DIRECTOR OF EXTRACTION, METC	5/11/19	800284007	5/93
ALAN STREB DEPUTY ASSISTANT SECRETARY OFFICE FOR CONSERVATION PROGRAMS	3/12/32	800353081	4/94
LOUIS DEMOUY CHIEF, INTERNATIONAL STATISTICS BRANCH	3/8/40	800079264	12/90
W. CALVIN KILGORE DIRECTOR, OFFICE OF ENERGY MARKETS AND END USE	5/6/43	800194443	5/92

FROM THE DEPARTMENT OF STATE:

STEPHEN GALLOGLY INTERNATIONAL ECONOMIST, OFFICE OF PRODUCTION AFFAIRS	9/5/53	900042401	7/92

CATHLEEN CAMPBELL 8/21/54 900091018 3/95
USSR PROGRAM OFFICER,
OFFICE OF COOPERATIVE
SCIENCE AND TECHNOLOGY
PROGRAMS

FROM THE DEPT. OF COMMERCE,
- A REPRESENTATIVE TO BE DETERMINED; AND

INTERPRETERS (2) YET TO BE DETERMINED,

FOR A TOTAL DELEGATION OF 16 MEMBERS.

Chronicle of Events

A chronicle of events related to the DOE fact finding mission to the Soviet Union, hosted by the Soviet Bureau for Fuels and Energy Complex and which occurred between July 14, 1990 and July 26, 1990 follows. The U.S. delegation consisted of representatives from DOE, IE, EIA, FE, and CE, from the State Department and from Commerce (see Delegation List). Fact finding was the primary purpose to the mission. An agreement for collaboration on non-nuclear energy issues is a potential outcome of this and future discussions.

The events described below are only those in which I was a participant and which may have some relevance to CE interests. Most of the meetings included many Soviet participants. Those which I have listed are only those who were most prominent in the relevant discussions.

Moscow, July 15 - Arrival and Delegation Planning Meeting

Bureau of Fuels & Energy Complex

G. D. Margulov, First Deputy Chairman USSR Council of Ministers, Bureau on Fuel and Energy Complex (Head of the Delegation)

Makarov, Aleksey, Director, Institute of Energy Research of the USSR Academy of Sciences

V. M. Vasilev, Deputy Head of the Department USSR Council of Ministers, Bureau on Fuel and Energy Complex

Guliaev, Yuriv, Academician, USSR Academy of Sciences

Harahashyan, Felix G., Sector Manager, State Gas Concern

Alekseev, A.M., Head of Office, Astrofizika Scientific & Industrial Amalgamalian

Bureau of Fuels & Energy Complex, July 16

- Margulov initiated discussions by introducing the Soviet participants and outlining the agenda for the ten day period to follow. Mr. Grundy, DOE/IE, responded and agreed to the proposed program.

- Makarov discussed the Soviet energy strategy and projection of long term energy needs based on several economic growth scenarios. He believes that it will take a "whole generation" for the Soviet states to achieve current western European living standards and substantial growth in energy demand. Energy conservation must be the "main thrust" of the energy program plan. Conservation measures will need to be introduced at a rate of 1.5 to 3 times faster than current practice. This will require adoption of best available world technology. Adoption of conservation must go beyond that which is economically justified. The industrial sector is seen as the area of greatest potential for energy savings. Makarov also mentioned the Moscow energy club and connected the club with the overall Soviet energy planned. He also noted that several Americans are participants including Sokolow, Schipper and Chandler.

- Vasilev spoke mostly of energy savings and ecological benefits. Energy use has grown steadily - 3%/year, but period of cheap energy is over. It is now time to include energy efficiency in overall plan. A decrease of 33% or more is possible through conservation. Structural changes are also needed to sustain economic growth. Improved efficiency is possible through better management and new technologies. Soviets must plan to abandon obsolete technology by 2000. Strict standards of performance are being developed and will be required. Energy savings can yield $60x10^6$ tonnes/year. Soviets have identified 60-80 technologies which are ready now for adoption (e.g. electric drives, automation, metering, controls, etc.) - but manufacturing is insufficient and better recognition is needed by end users. "Gasification of villages" (conversion to gas fueling) will improve efficiency by substituting gas for solid fuels. More combined heat and power systems will contribute. He proposes many more CNG powered vehicles - 2000 in place today with objective of 1.5 million cars. CNG also seen as marine fuel. He also proposes ecologically pure power - non traditional, nuclear, cheap hydrogen production(?)

- Margulov mentioned the formation of a "non-governmental international organization on energy efficiency and fuel substitution." (Is this the Moscow Energy Club?) Membership consists of 34 Soviet ministries - many foreign countries, some U.S. companies.

- Guliaev spoke of beneficial "Bioelectromagnetic Effects" resulting from very short wave radiation - millimeters. Had no information in response to questions on 50 hertz transmission line effects on human health or behavior.

Harahashyan stated that an "enterprise" has been developed to assess the national geothermal resource base. Geothermal currently used for non power applications (43% district heating, 45% agriculture, 10% industry, 2% power). First large power station currently planned for Kemchatca (100MWe). Need improved prospecting means to improve efficiency of measure-
measurement, though claim that they have fairly complete geothermal resource map. Would like to make resource logging the subject of a future bilateral. Comments also offered on valuable byproduct components from water streams and difficulties encountered with pumps, valves, etc.

- Alekseev A.M. presented an array of solar collector devices built by various Institutes. These included simple, low temperature, flat plate heaters and a variety of concentrating systems parabolic troughs and dishes with concentration up to "several thousand." He described the dish units ranging from one to 15 meters in diameter for multipurpose application including power generation to 20 Kw. The Soviet preference is for 2-axis parabolic concentrators, which are fitted with Brayton, Stirling, ORC, and Thermionic (more likely thermoelectric) conversion systems. Everything to date is experimental. They are nearing completion of a 500 watt Stirling Cycle (helium) system designed to operate at 5-600°C with conversion efficiency of 16%. Trials will begin this fall. He also mentioned the construction of two 5 meter units with thermal storage which will begin testing this year in the Crimea. They also have a program involving two fluid circuits (like LUZ?) but better because of dual axis orientation.

Novasibersk, Siberia, July 17

Mamon, Gennedy - Deputy Minister Regional Executive Comm.

Nakoriakov, Vladimer - Academician, Vice Chief, Siberian Department of Soviet Academy of Science

Director, Institute of Thermophysics

Kariamov, Anotoly - Vice Chief, Novasibersk Executive Committee

- Mamon spoke broadly of conservation as a key opportunity. Acknowledge ecology as a major problem in the USSR. Seem to have no comprehensive plan but are beginning to think of options. Expressed doubt that basic building envelope design could be altered very much or easily. Allowed that window glazing panels might be improved. Temperatures fall to as low as -65°F. Double and triple glass in common place. (My room had four glass panels - very unusual I'm sure for it is Gorbachev's room when he's here.) District heating is widespread. Distribution pipes are above ground on elevated supports and poorly (if at all) insulated. Spoke openly about need for greater autonomy - ability to make decisions and execute plans at a regional level.

Akademgorodok, Siberia, July 17

Serant, Felix, Chief Engineer, Siberian Ministry of Energy

- Nakoriakov explained that there are 35 institutes at Akademgorodok dealing with a wide range of disciplines. Employ 35,000 people and includes 100 members of the academy. They offer a large body of science to assist industry. Feel hampered by weak status of a non-defense industry. experimental equipment is described as nothing but "junk" at this point. The Institute of Catalysis is concerned with combustion science and exhaust gas treatment. The Institute of Mechanics is doing work on hydrogen as an energy source. Also working on advanced steam engines and thermodynamics of heat engines.

- ________________ - Institute of Catalysis

Working in surface chemistry in support of chemical industry and environmental problems developing improved combustion efficiency for poor fuels - specifically wet biomass. Also developing techniques to convert solar energy to chemical industry. Achieved 42% conversion to synthesis gas. Are working on high temperature fuel cells and thermal storage at low temperatures. Working with Catalytica - a U.S. company.

- Serant, Felix - Chief Engineer, Siberian Ministry of Energy

Commented on problem of introducing technology into industry - institute work is too basic. He is working with institutes and power stations to overcome problem of introduction.

- ________________ - Institute of Thermal Physics

Working in combustion, heat exchangers and steam generators. Have frequent contact with Allstrom. Also working on "secondary" energy systems - heat pumps in 300-500 Kw range. Investigating substitutes foe Freon 11 and 12 (Freon 12 was only example cited)

Zerinsk, Siberia - July 18

Mitiaev - Victor V., Director, Altai Coke Chemical Plant

A day to remember. Ten hours of driving over poorly developed roads at high speeds to see a modern, but conventional coke production plant. The plant consisted of five large coke oven batteries. It did have two or three dry quenching facilities. More than 1/2 the production was dry quenched process. Briquette coke making had been considered but according to Mitiaev was abandoned because it was considered to be economically marginal. (I don't know how to read this since they seem to have little concept of overall economics)

Kiev, Ukraine, July 19

Gritsenko, Anatoly V, First Deputy Power and Electrification of Ukr SSR

Lobamob, Leonid M, Deputy Director, Paton Welding Institute

Tonkal, Vladimir, E., Director Institute of Energy Saving Problems

Lobamob, Leonid M, Deputy Director, Paton Welding Institute

Tonkal, Vladimir, E., Director Institute of Energy Saving Problems Academy of Sciences of the Ukraine

Moveham, Boris, A., Head of Department Paton Welding Institute

Kolsnikov, Sergot, V., General Director, Energotechnologija and Informatika

Gladush, Victor D., Deputy Prime Minister of Ukraine

1' Atskevich, Stanislov, V., Deputy Head, Advanced Production and Ecology Department Ministry of Power & Electrification

Trypillyn Power Plant, July 19

Krasnochton, Nicoly, Director, Trypillin Power Plant

Kolesnikov, Sergei, Director, Power Plant Operations Training Center

- Krasnochton provided tour of major fossil fuel power station Trypillyn. This is a 2000 megawatt plant on the Dniepar river. Appears to be a reasonably modern well operated facility with an availability of about 78%. Questions concerning improvement in end use efficiency were answered vaguely. As with other contact with the Soviet, most energy people seen to have little concept of conservation or the potential for savings.

- Kolesnikov, Sergei, manages center which trains operators for entire country. Produces 100 operators/year and retraining for many more. Provided a tour of the training facilities with included several full size power plant operating station simulators. A plea was made for U.S. assistance to complete one of the facilities. Apparently, more powerful computing facilities are required to properly simulate the system.

Paton Institute, July 19

Lapanov, Leonid, Deputy Director, Paton Institute

- Lapanov, Deputy Director of highly recognized center for welding technology. Described numerous innovations including liquid and vapor depositing of controlled hi-alloy materials on low-alloy base for use in engines and other applications. Elaborate casting processes were described for the production of gas cooled turbine blades.

  A highly professional and interesting film history of the origin and accomplishments of the Institute was shown.

The Institute maintains close contact with many U.S. firms. Several U.S. firms hold license to Paton patents. J. Ray McDermott Company was mentioned over and over for some reason.

Moscow, July 20

Schenlin, Director Emeritus, Institute of High Temperature

V. M. Batenin, USSR Academy of Science Associate Member, Director of an Institute

- Batenin spoke broadly of the objectives of this strong institute -basic and applied research in the area of power engineering plus an experimental complex serving range of related needs. Budget comes from three sources - from the Academy for basic work, from State Committee for Science and Technology and from Industry (e.g. development of gas heaters with regeneration for gas dynamic lasers). He then summarized specific activity including - properties of materials, interaction of materials with high flux energy, composite materials, heat transfer at high flux, gas dynamics at high velocity and superconductivity Batenin then described current work in new energy technologies - MHD, coal gasification, efficient combustion, emission control and catalytic techniques involving no platinum or paladium and which are active at low temperature. The latter could be applicable to chemical processes.

  Papers were provided on the work in catalysis as well as several topics of potential mutual interest (e.g. industrial heat pumps).

Moscow, July 21

Ministry for Power & Electrification

Korsun, Juri N., First Deputy Minister of Energy and Electrification

Diakov, Anotoli F., Deputy Minister of Energy and Electrification

Korobof, Leonid, Deputy Minister of Energy and Electrification

Olkhovsky, Gurgen G., Director, All-Union Heat Engineering Institute

Davidov, Leonid, Dir General, VNPO-ENER-BOTEH-PROM

- Kurson lead off with an overview of Ministry generating 1722 trillion KW-hrs employing 2,000,000 people and 900 people in the Ministry itself.

- Diakov explained that he was concerned with generation and distribution of power. Also concerned with distribution of by product heat. System has capacity of 350 gigawatts 70% of which is thermal. Many units are obsolete and require updating. Ministry is also concerned with efficiency improvement at the demand side. State inspection office audits energy use to achieve high efficiency. Standards of acceptability or corrective measures were not made clear. Efficiency is considered to be very low because of fuel and energy cost. Laws are being drafted which will adjust prices. Price adjustment to be made to reflect environment impact. The Ministry is charter to date has only been supply - now being expanded to include demand.

  Replacement or new capacity will be provided in part by the defense establishment major emphasis will be placed on improved environmental acceptability. Unconventional sources of power (solar, wind, geothermal and small hydro) are also being studied. As capacity is added the use of natural gas will rise to a goal of 52%. New technologies will be used for used for both coal and gas to lower emissions.

- Olkhovsky all Union Heat Engineering Institute spoke of close relationship with EPA, Combustion Engineering, EPPI etc. Brochure provided on work of institute.

- Davidoff recently participated in RETSIE meeting. Presented a prepackaged unit residence built of environmentally acceptable materials and designed for extreme environment Secretary Watkins examined unit and suggested a Joint venture to build units on Mexican border for homeless and migrant workers. San Diego Gas and Electric also expressed interest. Joint meeting planned for August in San Diego.

Krzhizhanovski Institute, July 21

Gabrilov, Nicoly, Deputy Director, Krzhizhanovski Institute

Patapov, Oleg, Head of Low Grade Fuel Power Department

Deals with a wide range of power engineering technologies. Activities focused on combustion, combustion modeling, combustion of low grade fuel and emission controls. Doing studies of the relative economic of various fossil fuels and processing of shale oil, coal cleaning and ash removal.

This Institute is also the center for USSR work in solar thermal technologies. Are studying several configurations which combine photovoltaics and solar thermal claimed to have recent contact with Sandia and Howard Coleman on this subject. A publication was provided which describes some of their work.

Moscow, July 23

Bureau of Fuels & Energy, July 23

G. D. Margulov, First Deputy Chairman USSR Council of Ministers, Bureau of Fuel and Energy Complex (Head of the delegation).

- Margulov the purpose of this meeting was to summarize our findings to date and to present a preliminary draft of a the meeting record. Each of the members of the delegation made a brief presentation of their findings. Grundy summarized the meeting record. Margulov proposed a 5-7 day workshop to deal with all aspects of conservation. I suggested an alternative approach which would piggy back on relevant meetings which have already been planned (e.g. lighting and glazing) where many of our specialists already plan to attend. Margulov was not very keen on this idea. I recommend that we move very quickly to show that this concept can work because a general conservation workshop dedicated to US-USSR collaboration would be very inefficient and costly in my opinion. Fossil proposes to go forward with a workshop of limited scope.

Soviet Academy of Science, July 23, 1990

Rudenko, Yuriy, Academician, Soviet Academy of Science

- Rudenko explained that there are 17 departments within the Academy of Science - one of which is dedicated to the physical problems of energy. Each department has several institutes. The energy department has six institutes - four were emphasized - High Temperature Science, Chemical Physics, Energy Research (jointly supported by Academy and Ministries) and Atomic Energy. The Academy has been an aggressive supporter of international cooperation. With regard to the U.S. this primarily takes the form of joint efforts between the Soviet and U.S. academies of Science. Conservation has been the major topic for the last five years. Some of the major themes in this area include identification of promising energy efficient technologies, electric motors and generators, new steam generator types and advanced energy conversion. Other topics include: global problems of energy development and environment and nuclear plant safety. Rudenko mentioned the Moscow Energy Club and their recent meeting in Paris which dealt with some of these issues. The Club has recently begun publishing a magazine to promote collaboration.

  The activities of the Institute of Chemical Physics were broadly summarized. Activities of relevance to Conservation and Renewables include research on alternative refrigerants, instrumentation for monitoring performance and exchange arrangements with ORNL, EPRI, GRI and LBL.

The Energy Research Institute is engaging in strategic planning for the energy complex. With regard to conservation, the Institute seeks to establish data base and establish priorities for introduction of measures. They are also doing economic modeling to study effects of price. Have collaborative arrangements with EPRI and do a joint publication with Battelle.

In response to questions, Rudenko attempted to describe the relationship of institutes under the Academy versus those under the Ministries. The Academy is responsible for basic science while the Ministries are responsible for application of science. Yet another organization, the State Coordinating Body for Scientific Development serves to unite the work of the various institutes to achieve certain national goals.

<u>The Kremlin</u>

<u>Counsel of Ministers of USSR, July 23</u>

<u>Ryabov, Lev D., Deputy Chairman</u>

- <u>Ryabov</u> stated that the Bureau has broad responsibilities. The Soviet situation offers good opportunity for many U.S. companies. Energy savings potential is very large in the USSR and much needs to be done. He stated that our main task is to "rationalize" the use of energy for the economy and for the environment. In response to the U.S. Ambassador's statement relative to need for private sector credit and profit, he proposed joint venture as a solution to problem and specifically mentioned Polaroid as a model. Mr. Ryaboff emphasized the urgent need in the USSR of housing, more and better consumer goods and again mentioned the cooperation with the U.S. as an answer to these needs.

  He spoke openly of Chernobyl, describing it as a tragedy but also an opportunity to learn from ones mistakes to begin building for a future which could include a nuclear option.

<u>Krzhizhanovsky Institute, July 24</u>

<u>Popov, Vladmir A., Director, Doctor, Professor and Head of Laboratory at Institute</u>

<u>Voronkov, Mark E., Head of Energy Conservation at Institute</u>

<u>Koltun, Mark M., Head of Photovoltaic Laboratory at Institute</u>

<u>Vasilev, V.M., Deputy Head Council of Ministries, Bureau of Fuel & Energy</u>

- <u>Popov</u> presented information on a pulse combustion applied ceramic coating for use on wear surfaces and other surfaces subject to erosion and abuse. Provided copy (in Russian) of descriptive material. Process developed originally in U.S. He has refined process.

- Voronkov mentioned work in thermal storage for solar thermal systems and direct contact heat exchangers. No details provided.

- Koltun has worked in solar thermal for many years and published extensively. Presented a proposal for a hybrid solar photovoltaic a thermal energy system response desired. Also requested data on current cost and availability of small photovoltaic systems.

- Vasilev said that the Bureau for Fuels & Energy Complex faces three problems - forecasting, economics and implementation. In USSR conservation was in the past based on supply restrictions - this system is no longer operative and new mechanisms must be developed by end of this year. The potential for energy savings is between 800-1200 x 10^6 tons of coal equivalent per year. Need good diagnostic service to assess the full potential. Scientific establishment is prepared to develop the technology. Production of required equipment is the problem. Industry suffers from inertia and lack of automation. Modern prediction capability is required in following areas - engines for power generation, transportation equipment, consumer goods, housing, agriculture, and electronics. Estimated cost of this infrastructure is 5-6 x 10^9 rub.

  With regard to advanced lamp products, the technology itself is not seen as a problem. Large scale production facilities have been planned, but will cost 2.5 x 10^9 rub.

  Large losses currently exist in transmission lines because of reactive power losses. Equipment is needed to compensate for reactive losses. Apparently the Soviets lack the production capacity to produce the required reactive compensators.

  There are about 300,000 small boilers in the USSR. Most of them are old and inefficient and should be replaced. They currently contribute significantly to energy inefficiency and ecological problems.

  He also referred to "dry-furnaces" (I think this means "dryers") which typically are not recuperated and have poor insulation and burners. These represent a significant opportunity for energy savings through retrofit.

- Vorvarsky of the All-Union Scientific Research and Design Institute (VNIPIENERGOPROM) is dedicated to energy supply and conservation in industry. Examples of several successful project given including very large heat pumps to supply district heating requirements from a low grade source (Caspian Sea).

He is looking for joint venture partners for heat pump system. For this purpose he has been assigned a manufacturing space of 15,000 M^2. Over ten years a need for 5,000 megawatts of heat pump capacity. There is also an urgent need for insulated distribution pipe for district heating. Varvorsky is also looking for a joint venture partner to produce such pipe. Partner should have access to and experience with PolyIsoCyurinete insulation or other appropriate insulation system. Pipe size up to 140 cm diameter. Manufacturing space is available in several locations.

Ministry of Ferrous Metallurgy, July 25

Braun, Nikolai V., Department Chief of Coke Chemical Industry
Ministry of Iron & Steel

Vacalogen, Mechael 4

- Braun had been contacted early regarding our visit, and recommended that we first visit the Moscow facility and then Kharkov. He told me that we wasted our time going to Zerinsk -I didn't need to be reminded.

He commented first on the need for dry quenching. After 1998, no wet quenching will be permitted in Germany. Therefore, the Germans are moving quickly to install dry quenching. They are also working with the Soviets on alternative processes.

Braun first described a continuous process involving hot charging, tamping and dry quenching. The first large facility employing this technique will go into operation next year in Kommunersk.

He described a large pilot briquetting plant which is nearly complete in Niopropovinsk, Ukraine Plant, is designed for 500,000 tons/year, is 130M tall, completely automated and uses a wide range of coals including very poor grades. Soviets have stopped work because of funding shortage. Soviets presented paper on this system at meeting in Essen. Braun promised us a copy.

A second technique was briefly described as a single complex involving preheating tamping and dry quenching in a completely attached through process. This will be presented in U.K. at coke chemistry conference on September 27.

A third process is under early stage of development at small scale in Moscow laboratory. Described as a "rotary ring" in which coal is introduced at one point, baked and removed as coke at another point. A large unit incorporating this principle is currently being built at Kutaisi Zestofoni (?) Georgia.

The Germans are developing a large modular unit which meet all current objectives. No one has details.

Braun mentioned another alternative dry quenching process which they have developed. It involves the commingling of the discharged coke with the incoming charge - the sensible heat of the discharge dries and devolitizes the charge through direct contact. The coke and the coal are then separated - he refused to tell me how. The first pilot project is operating outside Kharkov at Krivoj-Rog Ukraine. The first production unit is planned for Zerinsk. The Germans are interested in this technique - but is still up for grabs.

The Soviets currently produced over 80 x 10^6 tons of coke annually. U.S. production is down to 20 x 10^6 tons.

RECORD OF THE U.S.-U.S.S.R. MEETING

ON NON-NUCLEAR ENERGY

A U.S. fact-finding delegation visited the U.S.S.R. July 15-25, 1990 to continue exploring potential bilateral cooperation in the field of non-nuclear energy. The visit reciprocated that made to the U.S. by a Soviet delegation in January 1990. The July visit was hosted by the Bureau of Fuels and Energy Complex (BFEC) of the U.S.S.R. Council of Ministers. The Soviet delegation was led by Grant Margulov, First Deputy Chairman of the Bureau of Fuels and Energy Complex. The U.S. delegation was led by Thad Grundy Jr., Deputy Assistant Secretary for International Affairs, U.S. Department of Energy. Members of the respective delegations are listed in Annex 1.

PLENARY MEETING IN MOSCOW

The first plenary meeting was held July 16 in Moscow. After welcoming re... .nd introductions by the heads of delegations, Mr. Margulov discussed the objectives and agenda (Annex 2) of the visit. He noted that this is a fact-finding visit, adding that the Soviet side was ready to provide detailed information on non-nuclear energy infrastructure, policy, and R&D developments.

In his opening remarks, Mr. Grundy conveyed greetings from DOE Deputy Secretary Henson Moore and Assistant

Secretaries John Easton, Robert Gentile, and Michael Davis. He stressed that the U.S. is interested in fact-finding on Soviet energy policy and objectives, the status of R&D for specific energy technologies, and the potential for developing a data and information exchange to support bilateral cooperation. Mr. Grundy observed that detailed discussions with the distinguished Soviet delegation should ensure the accomplishment of these objectives and potentially lead to recommendations to establish mutually beneficial activities. He emphasized the U.S. desire to explore Soviet goals and objectives for specific energy sectors and to focus on possible opportunities for energy R&D cooperation. He also emphasized the delegation's interest in discussing potential opportunities for the U.S. private sector to participate in Soviet energy development.

Mr. Margulov led the presentations on the Soviet energy outlook and current policies. [illegible]iet delegation made a series of presentations on key Soviet energy issues and programs. They offered recommendations on possible cooperative activities. In response, Mr. Grundy thanked the Soviet delegation for its excellent presentations and indicated that the U.S. side looked forward to the site visits and the opportunity to discuss these programs in greater detail.

SITE VISITS

Following the opening plenary session in Moscow, the U.S. delegation split into two groups. The first group traveled to Novosibirsk and Kiev. In Novosibirsk they discussed energy R&D with USSR Academy of Sciences officials in Akademgorodok. They also met with local Minenergo officials to discuss power generation, coal slurry pipeline development, light-weight stand-off insulators developed at Minenergo, district heating, and the energy data system supporting regional power generation and transmission. In Kiev the group met with officials from the Ukrainian Ministry of Power and Electrification and the Ukrainian Academy of Sciences' Paton Institute of Electric Welding.

The second group traveled to Noviy Urengoy, Yamburg, and Tyumen to visit natural gas and oil resource development areas. They met with Gazprom, production associations, and local officials to discuss regional energy policy; gas exploration and development; transportation issues; oil and gas recovery problems; and opportunities for U.S. firms.

From July 20-24 the U.S. delegation met with various Soviet energy organizations to discuss specialized topics that have potential for cooperation. These include MHD systems, gasification combined cycle systems, fluidized bed systems, combustion, waste recovery, heat pump research, enhanced oil recovery, horizontal drilling for gas, gas hydrates, gas recovery technologies, and emission control programs. Also discussed were replacement and retrofit of facilities with advanced technologies for combating pollution and improving efficiency; R&D in renewable programs (including solar, wind, biomass, and small hydro); oil shale extraction and combustion; and USSR energy information and data systems. Additional meetings were scheduled for July 25 to continue these discussions.

FINAL PLENARY MEETING

On July 23 the delegations reconvened in Moscow to review the results of the fact-finding visit and to discuss next steps. The sides agreed that the objectives of the fact-finding visit had been met. Both sides expressed interest in further consultations between U.S. and Soviet experts in the areas of energy policy and analysis, global energy markets, development of energy resources, and opportunities for U.S. companies in the Soviet Union. The Department of Commerce and other relevant U.S. government agencies would be involved in any such consultations. In addition, the sides agreed to build on the progress made in these talks in the areas of energy R&D; data and information exchange; and facilitation of discussions between the U.S. private sector and their Soviet counterparts. They also agreed to expedite meetings of experts, as follows:

1. U.S. and Soviet experts will meet in the U.S. to plan a joint workshop(s) on fossil energy systems to further define specific areas of mutual interest for possible cooperative activity. The workshop may consider topics such as coal power systems, coal based fuels, emission control systems and oil and gas extraction. U.S. industry will be invited to participate.

2. U.S. and Soviet experts will meet in the U.S. to identify specific data and information that might be sharea and to discuss technical issues associated with the collection, review, and dissemination of energy data.

On July 23, Mr. Grundy and members of the U.S. delegation, accompanied by Ambassador Matlock, met with Mr. Lev D. Ryabev, Deputy Chairman of the USSR Council of Ministers. They discussed the progress made during the fact-finding visit and the potential for joint activities. They also noted with satisfaction the next steps for cooperation on non-nuclear energy programs.

Done in Moscow, U.S.S.R., on July 24, 1990, in the English and Russian languages, both texts being equally authentic.

For the U.S. Department of Energy	For the Bureau of Fuels and Energy Complex of the Council of Ministers of the USSR
______________________	______________________
Thad Grundy Jr. Deputy Assistant Secretary for International Affairs	Grant D. Margulov First Deputy Chairman

Done in Moscow, U.S.S.R., on July 24, 1990, in the English and Russian languages, both texts being equally authentic.

For the U.S. Department of Energy

Thad Grundy Jr.
Deputy Assistant Secretary for International Affairs

For the Bureau of Fuels and Energy Complex of the Council of Ministers of the USSR

Grant D. Margulov
First Deputy Chairman

AGENDA

of the negotiations with the delegation of the USA Department of Energy on the problems of co-operation in the field of fuel & energy

July 16 1990

9-00 - 9-30	Opening remarks Presentation of members of the delegations	R. D. Margulov, First Deputy Chairman, Bureau of the USSR Council of Ministers for Fuel and Energy
9-30 - 10-00	Discussion of the programme of the visit	

Reports & presentations, answers & questions

10-00 - 11-00	The USSR Energy programme	A. A. Makarov, Corresponding Member of the USSR Academy of Sciences, Director of Institute for energy research of the USSR Academy of Scienses
Break 10 min.		
11-10 - 11-40	Actual researches in the field of energy conservation in the USSR	V. M. Vasiliev, Deputy Head of Office, Bureau of the USSR Council of Ministers for Fuel and Energy
11-40 - 12-00	Geothermal resources of the USSR	F. G. Harahashyan, State Corp. GAZPROM Dir. of Division

12-00 - 12-30	Clean coal technologies	V. V. Nechaev, Deputy Head of Department for Science and Technology, The USSR Ministry for Power & Electrification
12-30 - 13-00	Plasmo-chemical membrane modules for processing of hydrogen-sulpfur natural gases	V. D. Rusanov, Corresponding Member of the USSR Academy of Sciences, Head of Office, Institute of atomic energy by the name of Kurchatov
13-00 - 13-30	Creation of energy information system	F. Ya. Morozov, Director, Central Dispatching Department of the United Power System of the USSR V. I. Balanchevadze, Director, Main Computer Center, The USSR Ministry for Power & Electrification
13-30 - 15-00	Lunch time	
15-00 - 15-20	Bioelectromagnetic effect on human beings	Yu. V. Guliaev, Academician, The USSR Academy of Sciences, Director, Institute of Radio-electronics

15-20 - 15-40	Coal pulp pipeline	G. N. Delyagin, Dr., Deputy Head of Office, GIDROTRUBOPROBOD Scientific & Industrial Amalgamation
15-40 - 16-00	Gas hydrates	Yu. F. Makogon, Dr., Head of Laboratory, Institute of oil and gas problems, The USSR Academy of Sciences
16-00 - 16-20	Reconstruction & conversion of thermal power plants to combine steam-gas cycle	V. N. Ochotin, Dep. Dir Chief Engineer, TEPLOELEKTROPROEKT Institute
16-20 - 16-40	Use of associated petroleum gas [illegible]	S. M. Toplov, Head of Office, The USSR Ministry for oil & gas industry
16-40 - 17-00	Problems of petroleum & gas recovery on the Northern continental shelf with heavy ice situation	O. O. Sheremeta, Head of Office, The USSR Ministry for oil & gas industry
Break 10 min.		
17-10 - 17-40	Use of solar energy	A. M. Alekseev,, Head of Office, ASTROFIZIKA Scientific & Industrial Amalgamation
17-40 - 18-30	Discussion	

To whom it may concern.

Hereby I formally apply for a scientific associate or scientific post-doctoral position or a professorial fellowship at Your establishment. I may hope that my qualification will satisfy Your universally known high personnel standards. Enclosed is my Curriculum Vitae.

Sincerely Yours

S. Shapiro

Sergei Alexander Shapiro, Ph.D.

July 2.1990

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CURRICULUM VITAE.
S.A. Shapiro.

Current position:

-- Senior scientific-research worker in All Union Research Institute of geological, geophysical, and geochemical informational systems (VNIIGeoinformsystem) , Varshavskoe Shosse, 8, Moscow, 113105, USSR.

Personal data:

Name: Sergei A. Shapiro. *Address*:109518, Graivoronovscaia, 18-2-83, Moscow, USSR. *Place and date of birth*: Kursk, USSR, 6 June 1960. *Nationality*:Jew, *Citizenship*: USSR *Wife*: Inna Zhmodyak *Son*: Dmitriy Shapiro

Research interests:

Theory of waves propagation and scattering (in random, fractal, fractured, composite and porous saturated media); Wave phenomena computer modeling; Seismology (seismic waves scattering, attenuation, diffraction, seismicity, emission); Fractal and multifractal analysis applications (faults and cracks systems structures, rock surface forms and fragmentation); Seismic, VSP, and logging data processing, cross-hole tomography, migration; Acoustics (waves in bore holes, underwater and marine sediment acoustics, non destructive tessting, medical ultrasonics); Geophysics for civil engineering.

Major Accomplishment:

The theory of the connection between statistical moments of the random field and the wave attenuation coefficient values, measured in the seismology and acoustics, was developed. For the first time the fact of the reducing of the apparent attenuation of the direct seismic waves in random media, when the waves transfer from the weak fluctuation region to the strong fluctuation region, was shown with the use of this theory and experimentally. Some new methods of the separation of the elastic energy scattering and absorption characteristics of geological media were proposed. These theory and methods have been applied to cross-hole computer tomography, and they were included in the some methodical manuals for hole to hole sounding of some research institutes of USSR (VNIIgeoinformsystem, VNII Nuclear geophysics and geochemistry, and their branches, Moscow).

The theory of the elastic wave propagation, scattering and emission in the fractal medium, such as the medium with the discrete random inclusions distributed by their characteristic size by the power law or with the fractal inhomogeneities, was developed. It was applied to the explanation of the seismic waves attenuation coefficients dependences from the frequency, and fault systems fractal dimensions estimation.

Some new analytical results on the modes of wave motion in the thin fracture filled with a viscous fluid; on the elastic wave scattering cross section of the disk with any orientation and the shape likes a penny; on the acoustic pulse scattering by a rough surface and the pulse evolution in an anelastic media were obtained.

The method of the refraction seismic data computer interpretation on the basis of the seismic drift evaluation was developed and included in the methodical manuals for the geophysics for civil engineering (Moscow University, Geological Department).

Personal philosophy on the statistical model application in geophysics

The deterministic approach to direct and inverse problems of geophysics is highly developed and common today. The structures of geological objects (such as faults, pores systems, karst, plutonic bodies, hydrocarbon natural reservoirs, geosurfaces) and geological processes (such as earthquakes, emission, filtration) have a random character. I'm interested in the kind of statistical characteristics they can have; in the kind of information on the objects one can get from inverse statistical geophysical problem solving; and in the features of geophysical fields (wave and potential) in the statistical models (especially fractal like).

Education:

VNIIGeoinformsystem, USSR, 1987, Candidate Phys.-Math.Sci.
VNIIGeoinformsystem, USSR, 1986, Geophysics.
Moscow University, Geological Department, USSR: 1982, Diploma in Geophysical methods of mineral research and prospecting, Specialization in Seismology; 1980-Prediploma in Geology.
Moscow University,USSR:1980,Prediplomas in Physics, in Mathematics.
Moscow University, Geological Department, USSR, 1980, Begin of study in Geophysics. Moscow University, USSR, 1978: Begin of study in Physics and 1977-Begin of study in Mathematics. Moscow University, Geological Department, USSR, 1977 Begin of study in Geology.
School (public and high school) in Kursk, USSR, 1967-1977

Postgraduate professional education:

6/90	Courses of programming on the "C"language. USA-USSR Joint Venture "Dialog"(Microsoft Corporation representative),Center on the base of Moscow Engineering Physical Institute, Moscow.
4/86 - 4/90	All Union School for Young Scientists "Urgent Problems of Geophysics", Institute of the Earth Physics of Academy of Sciences of USSR, Suzdal, Zvenigorod, Rostov, Pereslavl Zalesski.
10/89	International Symposia, Geodesy - Seismology: Deformations and prognosis. Erevan, Armenia, U.S.S.R.
12/89	All Union Symposia "Non traditional methods of the geophysical research of inhomogeneities in the Earth's core." Institute of Earth Physics of Academy of Sciences of USSR, Zvenigorod.
10/88	Bulgarian School for Young Scientists "New geological and geophysical technologies.", Varna.
5/85	All Union Geoacoustical Symposia. All Union Research Institute of Nuclear Geophysics and Geochemistry, Moscow.
6/83	All Union Acoustic Conference, Acoustic al Institute of Academy of Sciences of USSR, Moscow.

Professional Experience:

since January 1989 Senior scientific-research worker at VNIIGeoinformsystem, Moscow, USSR.
1987-1989 - Scientific-research worker at VNIIGeoinformsystem,

Moscow, USSR.

1986-1987 - Junior scientific-research worker at VNIIGeoinformsystem, Moscow, USSR.

1982-1986 - Engineer and Junior scientific-research worker at All Union Research Institute of Nuclear Geophysics and Geochemistry, Moscow, USSR.

Courses taught:

at the Moscow University: Electro-, Gravitational-, Magneto-, Nuclear-Seismic- methods of prospecting; Physics of Earth; General Physics; Mechanics of continuum medium; Field theory; Radio-, Electro-ingeneering; Mathematical analysis; Analytical geometry; Linear algebra; Complection function analysis; Theory of probability and mathematical statistics; Numerical methods; Differential equations, Equations of mathematical physics; General-, Historical- and USSR Geology.

Teaching activities:

6/84 - 2/88	Cycle of the lectures at the seminar of Young Scientists at the Geological Department of Moscow University. Theme was "Scattering and attenuation of seismic waves".
4/88 - Present	Regular lectures at the seminars of VNIIGeoinformsystem, Moscow. Theme are "Fractal analysis in geophysics"; "Pulse evolution in anelastic media"; "Method of seismic data inversion".
5/89 , 11/89	Lectures at the International Institute of Theory of Earthquake Prognosis and Mathematical Geophysics Acad Sci USSR at the seminar of prof.A. Levshin, the theme was "Seismic wave attenuation in the weak and strong fluctuation region", and at the seminar of prof. V.E.Pisarenco, the theme was "Wave scattering by fractal fault systems".

Advisor for graduate students:

Svetlana Bidikhova, Geological department of Moscow University., Theme is "Cluster analysis application to the hole to hole sounding data processing" (89-90).

Professional activities:

Membership: Physics Society of USSR; *Languages*: Russian - mother tongue, English - good; French - poor. *Computing experience:* Knowledge of Basic, Fortran, C. Experience of work with PC IBM and PDP compatible computers.

PUBLICATIONS of S.A. SHAPIRO.

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3. Liakhovitskiy, F.M., Shapiro, S.A. and Gurevich, B.Y., 1983, The new

algorithms of the machine processing of the engineer seismic refraction data. In "Geophysical methods in the hydrogeology and engineer geology." Vilnius, 28-29. (in Russian).
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12.Smirnov,A.V., Misina,L.G, and Shapiro, S.A., 1986, Tube wave attenuation in the cased and open holes., Institute of nuclear geophysics and geochemistry, Moscow, Deponent in VINITI, No 3199-B.86, 4 pp. (in Russian).
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crete inhomogeneities (in application to the hole to hole sounding). Avtoreferat of phys.-math.sci.candidate dissertation, VNIIGeoinformsystem, Moscow, 22 pp. (in Russian).
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Methodical manuals:

1. Methodical manuals on the seismoacoustical noise in bore holes investigation.1983, (VNII Nuclear geophysics and geochemistry); 1988,(VNIIGeoinformsystem.)
2. Methodical manuals on the hole to hole sounding, 1985 (VNII Nuclear geophysics and geochemistry);1988,(VNIIGeoinformsystem.)
3. Methodical manual on seismic refraction application to civil engineering. 1982 (Moscow University.)

Real application:

The methods and computer programs have been applied to the investigation of the polimetallic ore bodies in the Uzbekistan and Ukraine and the foundations of the objects of civil engineering in Moscow.

Perspective research plans:

I'd like to continue the research in the theory and computer modeling of the wave propagation, scattering and emission in random and fractal media;
-in the processing of the seismic and seismicity data for the scattering and absorbing properties and statistical and structure characteristics of media and of earthquakes investigation;
-in the fractal and multifractal analysis applications to the geological objects and processes investigation.

I intend to start the research in the inverse statistical geophysical problem solving:
- in the investigation of features of geophysical potential fields in statistical and fractal models;
- in the application of the random wave field theory to the waves in bore holes, underwater and marine sediment acoustics, non destructive testing, and medical ultrasonics.

I intend to write a book on the seismic waves in random media, there is some material of it in my Ph.D.thesis.

S. Shapiro

S. Shapiro

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Soviet-American Monograph on Geothermal Energy

To: Patrick Muffler, Hugh Murphy, John Lund
All American Co-Authors

Subject: Initiation of the Monograph !

Date: March 30, 1990

This is the first general news memo on the status of the Soviet-American Monograph on Geothermal Energy. The Monograph was Project 4 of the Stanford University - Leningrad Mining Institute Geothermal Agreement. The other three projects were for joint research projects that require external funding. We have had difficulty in finding external research participants and sources of external funding for the joint projects. Since Stanford will not support the initial expenses necessary to generate the Agreement program and a draft of a proposal for funding, we have had to put the SU-LMI Agreement on hold. We plan to seek support from another institution in California willing to work together with LMI.

However, this does not affect the decision made in Leningrad to proceed with the Monograph independent of success of Government funding of the three joint research projects. In fact, it was considered better to have the Monograph be prepared by individual experts in geothermal energy as an independent group.

Accordingly, we have sent the enclosed letter to LMI to initiate the Monograph. Also enclosed are copies of the current List of Chapters with the names of the American co-authors and our suggested Outline to initiate preparation of the Chapter contents. On response to our letter, we would hope to start correspondence between each pair of Co-Authors. It takes about six weeks (minimum) for an exchange of correspondence by mail. Perhaps this might be an appropriate time for each of us to consider what we feel would be best coverage for our specific Chapter. Please send me any comments or suggestions you might have at this early stage. I will distribute a second news memo as soon as I hear from LMI.

Sincerely,

Paul Kruger

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Fax 415-725-8662

30 March 1990

Prof. Yuri D. Dyadkin
Leningrad Mining Institute
21st Linia - No.2
Leningrad 199026, USSR

Dear Yuri:

Your package arrived this week with your New Year card and the beautiful book on the Leningrad Mining Institute. It brought back many pleasant memories. Did you receive the book on the San Francisco earthquake?

We have not received the Agreement that you wrote me was signed in December. I regret very much that Stanford is unable to continue with the Agreement, except that we will continue the Soviet-American Monograph on Geothermal Energy and hope that conditions improve in the near future. As I wrote you previously, I will try to move the Agreement to another institution in California.

I enclose the 3 volume lists of the 26 American authors who have agreed to work with a Soviet co-author for preparing the 26 Chapters of the Monograph. Also enclosed is a Draft of a generic Outline which could be useful to initiate correspondence between the American and Soviet co-authors. We would appreciate receiving from you a list of the 26 Soviet co-authors and their address and your comments and suggested changes for the generic Outline. We anticipate that each pair of co-authors would, by correspondence, prepare a specific Outline for their Chapter.

We look forward to our continued collaboration,

With the very best wishes,

Paul Kruger

cc: P. Muffler, Edi., Vol. 1
H. Murphy, Edi., Vol. 2
J. Lund, Edi., Vol. 3
all American Co-Authors

Suggested Chapter Outline for First Drafts

Section	Responsible Co-Author for First Draft
I. Introduction	
Overall Objective of Chapter (general items to be covered)	*
Brief History of Topic	*
Basic Definitions	*
General Characteristics	*
II. Summary of Past Experience	
USA	A
USSR	S
World	*
III. Current Status of Development	
USA	A
USSR	S
World	*
IV. Future Expectations	*
and Research Needs	*
V. Discussion and Conclusions	*
VI. References	#

A = American Co-Author
S = Soviet Co-Author
* = by choice between co-authors
# = as compiled

GEOTHERMAL ENERGY
Joint Soviet-American Monograph
in Three Volumes
1992
(30 March 90)

Volume 1 Resources

Volume Editors
V. Kononov, Council for Geothermal Research AS,USSR
P. Muffler, U.S. Geological Survey

Chapter Authors

1.1 Nature of Geothermal Energy
USSR:
USA: Wendell A. Duffield (USGS)

1.2 Heat Flow Distribution and Geothermal Anomalies
USSR:
USA: David D. Blackwell (SMU)

1.3 Resource Base and Resource by Type
USSR:
USA: L. J. Patrick Muffler (USGS)

1.4 Exploration Geosciences (geology,geophysics,geochemistry)
USSR:
USA: Phillip M. Wright (UURI)

1.5 Prospect Evauation
USSR:
USA: Norman E. Goldstein (LBL)

GEOTHERMAL ENERGY
Joint Soviet-American Monograph
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Volume 2 Extraction

Volume Editors
E. Boguslavsky, Leningrad Mining Institute
H. Murphy, Los Alamos National Laboratory

Chapter Authors

2.1 Characteristics of Geothermal Reservoirs
USSR:
USA: Paul Kruger (SGP)

2.2 Drilling and Completion of Geothermal Wells
USSR:
USA: John C. Rowley (LANL)

2.3 Well and Reservoir Testing
USSR:
USA: Mohinder S. Gulati (Unocal)

2.4 Reservoir Diagnostics
USSR:
USA: Bruce A. Robinson (LANL)

2.5 Reinjection
USSR:
USA: Roland Horne (SGP)

2.6 Stimulation
USSR:
USA: Ralph Veatch (Amoco)

2.7 Artificial Geothermal Systems
USSR:
USA: Hugh Murphy (LANL)

2.8 Heat and Mass Transfer Processes in Geothermal Systems
USSR:
USA: Ping Cheng (Univ of Hawaii)

2.9 Management and Economics of Geothermal Fields
USSR:
USA: Subir K. Sanyal (Geothermex, Inc.)

2.10 Potential for Magmatic Heat Extraction
USSR:
USA: James C. Dunn (Sandia)

GEOTHERMAL ENERGY
Joint Soviet-American Monograph
in Three Volumes
1992
(30 March 90)

Volume 3 Utilization

Volume Editors
G. Gaidarov, All-Union Res Inst of Geoth Probs
J. Lund, Oregon Institute of Technology

Chapter Authors

3.1 Spheres of Utilization
USSR:
USA: Gerald W. Huttrer (Geothermal Management Co)
+ (P. J. Lienau Geo-Heat Center, OIT)
3.2 Thermodynamics of Conversion Processes
USSR:
USA: Ronald DiPippo (SE Mass. Univ)
3.3 Electric Power Plants and Steam Cycles
USSR:
USA: Richard Cambell (Ben Holt Co.)
3.4 Binary Conversion Cycles
USSR:
USA: Kenneth E. Nichols (Barber-Nichols Engr Co)
3.5 Advanced Conversion Cycles
USSR:
USA: Carl Bleim (EGG, ID)
3.6 Basic Direct heat Technology
USSR:
USA: Gene Culver (Geo-Heat Center, OIT)
3.7 Municipal Heat Supply Systems
USSR:
USA: Kevin Rafferty (Geo-Heat Center, OIT)
3.8 Industrial Heat and Mineral Extraction
USSR:
USA: Dennis T. Trexler (+ T. Flynn) (Univ Nevada,LV)
3.9 Agricultural and Aquacultural Heat Supply
USSR:
USA: Rudi Schoenmackers (New Mexico St. Univ)
3.10 Thermal Water Balneology
USSR:
USA: John W. Lund (Geo-Heat Center, OIT)
3.11 Environmental Aspects of Geothermal Power Engineering
USSR:
USA: Dwight L. Carey (Environ. Mangmt. Assoc., Inc)

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February 7, 1990

Dr. Phillip M. Wright
University of Utah Research Institute
391 Chipeta Way, Suite C
Salt Lake City, UT 84108

Dear Mike:

This letter is an invitation to you to participate in a Soviet-American joint project to prepare a 3-Volume Monograph on Geothermal Energy by becoming a U.S. author for one of the chapters with a Soviet co-author to be named in the USSR.

The project is one of several included in a Cooperative Agreement between the Leningrad Mining Institute and Stanford University for joint studies in geothermal energy development. The project objective is the publication (in equivalent Russian and English texts) of a compilation of research results of the USSR and USA and published literature of other countries in the topics of resources, extraction, and utilization of geothermal energy.

Enclosed for your review is a copy of the Preliminary Table of Contents with the names of the Soviet and American Editors who have agreed to assist in preparing the three volumes. Pat Muffler joins me in inviting you to prepare Chapter 1.4 on Exploration Geosciences (geology, geophysics, geochemistry).

At the present time, we are formulating the list of U.S. co-authors and have invited the Soviet Co-Editors to visit Stanford this Spring to finalize the arrangements for preparation and publication of the Monograph. We anticipate a publication date of about 1992 with a prior technical meeting of the co-authors in Leningrad to review the Monograph chapters and to finalize the equivalence of the Russian and English texts.

We hope very much that you are able to accept this invitation and look forward to working with you in what could be a very stimulating experience. Please let me know if wish to participate in the project. If there is any further information you may need, please do not hesitate to call.

Sincerely,

Paul Kruger

Paul Kruger

CC: P. Muffler, USGS

GEOTHERMAL ENERGY

USSR-USA Joint Monograph
(estimated 600 pages in 3 Volumes)
(for publication in 1992)

Chief Editors
Yuri D. Dyadkin (Leningrad Mining Institute, USSR)
Paul Kruger (Stanford University, USA)

Volume 1. Resources (Volume Editors: V. Kononov, P. Muffler)

1.1 Nature of Geothermal Energy
1.2 Heat Flow Distribution and Geothermal Anomalies
1.3 Resource Base and Resources by Type
1.4 Exploration Geosciences (Geology, Geophysics, Geochemistry)
1.5 Prospect Evauation

Volume 2. Extraction (Volume Editors: E. Boguslavsky, H. Murphy)

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2.2 Drilling and Completion of Geothermal Wells
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2.5 Reinjection
2.6 Stimulation
2.7 Artificial Circulation Systems
2.8 Heat and Mass Transfer Processes in Geothermal Systems
2.9 Management and Economics of Geothermal Fields
2.10 Potential for Magmatic Heat Extraction

Volume 3. Utilization (Volume Editors: G. Gaidarov, J. Lund)

3.1 Spheres of Utilization
3.2 Thermodynamics of Conversion Processes
3.3 Electric Power Plants and Steam Cycles
3.4 Binary Conversion Cycles
3.5 Advanced Conversion Cycles
3.6 Basic Direct Heat Technology
3.7 Municipal Heat Supply Systems
3.8 Industrial Heat and Mineral Extraction
3.9 Agricultural and Aquacultural Heat Supply
3.10 Thermal Water Balneology
3.11 Environmental Aspects of Geothermal Power Engineering

Russian Monograph

Confusion between Paul, Patrick, me,
Goldstein –

Norm suggests we switch chapters of me

~~the~~ Patrick →

Disposition:

SUGGESTED OUTLINE AND CONTENTS

1.4 EXPLORATION GEOSCIENCES

INTRODUCTION

2 Objective of Chapter.
To review application of geological, geochemical, and geophysical techniques to regional exploration for geothermal resources.

4 History of Geothermal Exploration.
Brief summary of early development, techniques used, philosophy.

3 Summary.
Summary of exploration methods and exploration strategies.

REVIEW OF REGIONAL EXPLORATION TECHNIQUES

2 Introduction.
Classification of techniques. Comparison of techniques used to those used for mining and petroleum exploration.

10 Geological Techniques.
Geologic mapping; study of drill samples; age dating; structural studies; geologic interpretation.

20 Geochemical Techniques.
Chemistry of thermal fluids; major, minor and trace elements in rocks; hydrothermal alteration; isotope studies; fluid-inclusion studies;

20 Geophysical Techniques.
Thermal techniques; electrical techniques; gravity techniques; magnetic techniques; seismic and seismological techniques; remote sensing.

REGIONAL EXPLORATION STRATEGIES

2 Introduction.
Summary of application of geosciences; exploration strategies.

4 Regional Area Selection.
Characteristics of geothermal environments (arid, wet, crystalline-rock, volcanic-rock, sedimentary-rock).

6 Regional Exploration.
The exploration process; regional exploration strategies.

EXPLORATION CASE STUDIES

2 Introduction.
Geothermal provinces in the U. S.; summary of regional exploration in the U. S.

10 Exploration of the Basin and Range, western U. S.

(10) Exploration of the Imperial Valley

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Thermal techniques; electrical techniques; gravity techniques; magnetic techniques; seismic and seismological techniques; remote sensing.

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EXPLORATION CASE STUDIES

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Geothermal provinces in the U. S.; summary of regional exploration in the U. S.

Exploration of the Basin and Range, western U. S.

Exploration of the Imperial Valley, southwestern U. S.

FUTURE EXPECTATIONS AND RESEARCH NEEDS

Introduction.

The future of geothermal exploration in the U. S.

Research needed to improve exploration techniques.

DISCUSSION AND CONCLUSIONS

REFERENCES

GLOSSARY

Rough estimate of pages, double spaced, typed = 110 without illustrations. Add 20 for illustrations.

1.3. Exploration Geoscience

1.3.1. Introduction - Wright

1.3.2. Review of regional exploration technique

A. Classification of techniques - Wright

B. Geological techiques - Leonov

~~*) volcanic areas - Leonov~~

~~**) non-volcanic areas -~~

~~C. Geophysical technique -~~

*)

**) spatial migration of volcanic and hydrothermal phenomena

***) morphology changes of thermal feeders

C. Geophysical techniques - Zubin

*) physical basis

**) geophysical researches of Kamchatka geothermal areas

D. Geochemical technique - Kononov

*) chemical classification of thermal fluids

**) chemical indicators of geotemperatures

1.3.3. Regional ~~strategy~~ exploration strategies - Wright

I.3. Научные основы разведки
(геология, геофизика, геохимия)

Для рациональной организации поисков и разведки месторождений термальных вод и парогидротерм на предпоисковой (прогнозной) стадии, а также I подстадии общих поисков еще до начала бурения необходимо провести в исследуемом районе комплекс геологических, геофизических и гидрогеохимических исследований, которые позволят составить общее представление о наличии (или отсутствии) часто непроявленных на поверхности геотермальных ресурсов, их объеме, качестве и тепловом потенциале. Такие исследования позволяют уже на предварительном этапе разведки гидротермальных систем, определить наиболее перспективные участки добычи теплоносителя и помочь в более правильном выборе мест заложения буровых скважин.

1.3.2В I.3.2. Геологические предпосылки поиска геотермальных месторождений

Леонов В.Л.

Рассматривая геологические условия проявления гидротермальной деятельности, остановимся на трех вопросах, которые могут быть важны при изучении любых геотермальных месторождений в любой точке земного шара. Прежде всего это типизация геотермальных районов. Она позволяет составить общее представление о месторождении еще до начала его разведки, сделать заключение о его перспективности и возможной длительности существования в нем гидротермальной активности. С другой стороны, это оценка расположения и возраста региональных геологических структур, определение закономерностей их развития. Такая оценка позволяет уже на предварительном этапе разведки территории определить наиболее перспективные районы, а в пределах конкретных геотермальных полей - определить участки, где могут быть вскрыты наиболее продуктивные зоны. Наконец, третий вопрос, - это возможность переориентировки магмо- и флюидопроводящих каналов с глубиной. При разведке геотермальных месторождений

Леонов В.Л.

Институт вулканологии ДВО АН СССР

13.1 ГЕОЛОГИЧЕСКИЕ ПРЕДПОСЫЛКИ ПОИСКА ГЕОТЕРМАЛЬНЫХ МЕСТОРОЖДЕНИЙ

Рассматривая геологические условия проявления гидротермальной деятельности, ~~я бы хотел~~ остановимся на трех вопросах, которые могут быть важны при изучении любых геотермальных месторождений в любой точке земного шара. Прежде всего это типизация геотермальных районов. Она позволяет составить общее представление о месторождении еще до начала его разведки, сделать заключение о его перспективности, и возможной длительности существования в нем гидротермальной активности. ~~о вероятном наличии непроявленных на поверхности геотермальных ресурсов.~~ С другой стороны, это оценка расположения и возраста региональных геологических структур, определение закономерностей их развития. Такая оценка позволяет уже на предварительном этапе разведки территории определить наиболее перспективные районы, а в пределах конкретных геотермальных полей - определить участки, где могут быть вскрыты наиболее продуктивные зоны. Наконец, третий вопрос, ~~на котором мне бы хотелось остановиться,~~ это возможность переориентировки магмо- и флюидопроводящих каналов с глубиной. При разведке геотермальных месторождений знание этих явлений также может оказаться очень полезным. ~~и помочь в более правильном выборе мест заложения буровых скважин.~~

Существующие попытки проведения типизации геотермальных районов на основе ~~тектоники геотермальных районов на основе~~ тектоники плит с выделением геотермальных районов, расположенных в зонах спрединга, зонах субдукции и в пределах внутриплитных аномалий [20, 23 и др.], ~~как мне~~ кажутся, не совсем удачны. Согласно этим классификациям к одному типу мы должны относить Йеллоустон и Гавайи (внутриплитные аномалии), но они совершенно не похожи ни по составу слагающих их пород, ни по скорости протекающих в них магматических процессов, ни по типу теплового питания приуроченных к ним гидротермальных систем. Вулканические и геотермальные районы Камчатки, которая согласно этим классификациям относится к зонам субдукции вряд ли могут сопоставляться с подобными районами Анд Южной Америки или Центрально-Американских стран, которые также относятся к зонам субдукции. В качестве примера можно сравнить историю развития кальдерных комплексов Атитлан в Гватемале [21] и Карымского центра на Камчатке [3]. Для первого установлено три цикла кальдерообразования с возрастом (млн.лет): 14–11, 10–8 и 1–0; для второго – шесть циклов с возрастом (млн.лет); 2, 0,8, 0,18 – 0,14, 0,11–0,08, 0,015 и 0,008. Можно привести и другие примеры – все они свидетельствуют о том, что скорость протекания магматических процессов в этих районах существенно отличается и что геотермальные районы в них также должны иметь отличия. На это обратил внимание также М.Бейкер [10], который сравнил развитие сложных кальдерных центров Центральных Анд, юго-запада США и Мексики, с одной стороны, и Японии, Индонезии и Новой Зеландии, с другой стороны. Он пришел к выводу, что во-первых, развитие происходит за счет малого числа выбросов, в основном игнимбритов, а во-вторых, в результате большого числа относительно мелких извержений как лав, так и пирокластики, и что эти отличия связаны, по-видимому, с мощностью земной коры. Этот вывод мне кажется очень важным – именно мощность земной коры должна лежать в основе типизации геотермальных районов. Попытка проведения такой типизации представлена в таблице 1. Выделено три типа геотермальных районов, связанных, соответственно, с океанической, переходной и континентальной земной корой. Различия между ними в периодичности главных эруптивных циклов, в составе продуктов вулканической деятельности и, особенно, в длительности фаз гидротермальной активности, по имеющимся данным, очень большие. В то же время природа не хочет подчиняться и этой классификации. Так, лишь условно можно отнести ко второму типу геотермальные районы зоны Таупо в Новой Зеландии. По составу продуктов, длительности фаз гидротермальной активности и по ряду других геологических характеристик эти районы ближе к третьему типу. Недавно было проведено сравнение зоны Таупо с районом Йеллоустона в США [30] и показано, что они имеют много общего. Но при близких размерах, объемах вулканических пород, скорости поступления магмы, зона Таупо отличается от Йеллоустона более короткими магматическими циклами, отсутствием резургенции, более молодой раздробленной корой. Эти условия препятствуют формированию

Таблица I

ТИПИЗАЦИЯ ГЕОТЕРМАЛЬНЫХ РАЙОНОВ
(по мощности земной коры)

Тип геотермального района	Тип земной коры	Мощность земной коры, км	Периодичность фаз повышенной вулканической активности, лет	Преобладающий состав продуктов вулканизма	Длительность фаз гидротермальной активности, лет	Примеры геотермальных районов (цифры – мощность земной коры, км)		Примечание
I	Океанический	до 20	10^2–10^4	базальты	1–10^2	Ассаль (Джибути) RISE (Тихий океан) Пуна, Лоихи (Гавайи)	5 5-7 12-17	Скорость растяжения земной коры ≥ 2 см/год
					1–10^3	TAG (Атлантический океан) Депрессия Данакиль (Эфиопия) Крафла, Рейкьянес (Исландия) Серро – Прието (Мексика)	10 12 15-20 17-20	Скорость растяжения земной коры <2 см/год
II	Переходный	20-35	10^4–10^5	андезиты	10^3–10^4	Олкария (Кения) Гейзеры (США) Камоджанг, Диенг (Индонезия) Палинпинон, Тонгонан (Филиппины) Албани, Сабатини (Италия) Хохи, Курикома (Япония) Паужетский, Мутновский (Камчатка)	20 20 20-25 25 25 25-27 26-28	
				риолиты	10^4–10^5	Вайракей (Новая Зеландия)	36	
III	Континентальный	40-60	$n \times 10^6$	риолиты	$n \times 10^6$	Еми – Кусси (Чад) Йеллоустон, Лонг-Вэлли (США) Эль-Татио, Калабосос (Чили)	45 40-50 60	
		до 80		–		Фанг, Сан-Кампьенг (Таиланд) Пуга-Чуматанг, Парбати (Индия) Янгбаджан (Китай)	45 60 70	Проявления вулканизма отсутствуют

Данные о периодичности вулканической активности, о длительности фаз гидротермальной активности и о скорости растяжения земной коры взяты из работ [3, 7, 15, 18, 21, 28 и др.] .

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достаточно крупных магматических камер на верхнекоровом уровне и не приводят к развитию таких сложных петрологических эволюционных процессов в магматических камерах, какие устанавливаются в кальдерных центрах запада США. Эти отличия необходимо иметь в виду и при сравнении геотермальных районов запада США и Камчатки. В частности, на Камчатке, которая также отличается молодой раздробленной корой, вряд ли можно ожидать нахождение крупных захороненных магматических камер, не проявляющихся на поверхности, подобно таким, какие установлены в районе Сокорро и в Долине Смерти в США. Особо в таблице I показаны геотермальные районы, расположенные в Гималаях. Мощность земной коры в этих районах – максимальная на Земле (до 80 км). В них не проявлена современная вулканическая активность, а тепловое питание осуществляется за счет продолжающих остывать крупных масс гранитов миоцен-плиоценового возраста.

Кроме мощности земной коры важную роль в развитии вулканических и гидротермальных процессов играет также, по-видимому, скорость растяжения земной коры, что было наглядно показано на примере гидротермальных систем, расположенных на срединно-океанических хребтах [7].

Все срединно-океанические хребты были разделены на высокоспрединговые (со скоростью растяжения более 2 см/год) и низкоспрединговые (со скоростью растяжения менее 2 см/год). При этом было показано, что на первых повторяемость циклических максимумов вулканической активности может быть в IO-IOO раз чаще, чем на вторых. Условия растяжения (по крайней мере, в плейстоцене) характерны также и для геотермальных районов в зонах субдукции. Однако скорости растяжения здесь значительно меньше. В вулканическом районе Кагосима на юге Японии – 0,2 мм/год [I6] в зоне развития новейших разрывных нарушений на Восточной Камчатке – 0,3 мм/год [4], а в вулканической зоне Таупо в Новой Зеландии – около 7 мм/год [26]. Не исключено, что относительно высокая скорость растяжения земной коры в зоне Таупо и явилась причиной отмеченных выше особенностей ее развития – повышенной частоты извержений, большого объема и преимущественно риолитового состава продуктов извержений.

Приведенные данные показывают, что на начальной стадии разведки геотермальных ресурсов, при поисках близких по типу геотермальных месторождений необходимо прежде всего обращать внимание на мощность земной коры, поскольку именно она определяет способ теплового питания геотермальных месторождений (частые внедрения базальтов или крупные длительно остывающие очаги кислых магм) и длительность их существования. Кроме того, важным фактором является скорость растяжения земной коры, которая также, по-видимому, может внести существенные изменения в геологические условия проявления гидротермальных процессов.

~~Другой аспект, который, с нашей точки зрения,~~ играет Важную роль при разведке геотермальных ресурсов, ~~это~~ последовательная миграция вулканических проявлений в каком-либо направлении. Рассмотрим это явление и его значение для геотермальных исследований на примере центрального участка Восточной Камчатки (рис. I). С юго-запада на северо-восток здесь происходит: общее "омоложение" пород от преимущественно плиоценовых до средне-верхнечетвертичных, уменьшение диаметра купольно-кольцевых структур, выклинивание зоны новейших разрывных нарушений [6]. Расположенные здесь гидротермальные системы приурочены к осевой линии участка и с юго-запада на северо-восток мощность их последовательно увеличивается (рис. I). Самые мощные высокотемпературные гидротермальные системы здесь как и в целом на Камчатке, связаны с вулканическими центрами, заложившимися или проявлявшими наибольшую активность в средне-верхнечетвертичное время [5].

Отмеченное явление, которое можно определить, как последовательную миграцию вулканизма с юго-запада на северо-восток, отчетливо проявляется и на примере отдельных вулканических центров (рис. 2). Кальдеры на них несколько смещены к северо-востоку относительно центров вулканических структур, на которых они формируются, а посткальдерный вулканизм, который в основном сосредотачивается внутри кальдер, со временем смещается к северо-востоку, перекрывает границы кальдер и распространяется далее на северо-восточных их склонах.

Анализ распределения термопроявлений на этом участке также показывает,что наиболее крупные из них тяготеют к северо-восточным и восточным частям вулканических центров, к которым они приурочены. Отчетливо проявлена эта закономерность и на примере других геотермальных районов Камчатки (рис. 3). Обращает на себя внимание и еще одна особенность – то, что миграция вулканизма и смещение термопроявлений происходят не просто к северо-востоку вдоль оси участка, но на отдельных центрах еще и к востоку в сторону фронта вулканической дуги.

Рассматривая подобные структуры ~~районы на рубежах~~, можно отметить также районы Йеллоустонской кальдеры. Последняя расположена на северо-восточном окончании протяженной вулканической зоны реки Снейк. Вулканизм в этой зоне последовательно омолаживается к северо-востоку [25]. Термопроявления сосредоточены внутри кальдеры и к северо-востоку от нее в бассейне р.Йеллоустон [14]. На о.Гавайи, расположенном на восток-юго-восточном окончании Гавайского хребта, проявляется ~~расположен~~ самый молодой вулканизм, а к крайней восток-юго-восточной части острова приурочены ~~район распространения~~ современные высокотемпературные гидротермальные системы [9]. Район Гейзеров в Калифорнии расположен вблизи северо-западного окончания протяженной области развития вулканических пород, последовательно омолаживающихся к северо-западу [17]. Такое же положение занимает гидротермальная система вулкана Ньюберри – она приурочена к ~~запад-северо-западному окончанию~~ вулканической зоне Бразес. В пределах этой зоны вулканизм последовательно омолаживается в запад-северо-западном направлении [19, 25]. Данные геофизических исследований показали, что перспективные в геотермальном отношении районы располагаются на склонах вулкана к западу от кальдеры [13].

Приведенные данные позволяют сделать вывод, что в подобных районах ~~подобных вышеописанным~~ (где в определенных направлениях происходит последовательное уменьшение возраста вулканических проявлений), там, где сосредоточены наиболее молодые проявления вулканизма, располагаются и наиболее крупные гидротермальные системы. Причем и сами эти системы несколько смещены (в том же направлении, в котором омолаживается вулканизм) относительно расположенных вблизи вулканических центров.

В то же время это заключение нуждается в уточнении. Так, на Камчатке оно справедливо для плиоцен-четвертичного этапа вулканизма в целом, но наиболее поздние проявления вулканизма (поздне-плейстоцен-голоценовые) ему не подчиняются или подчиняются только частично (рис. I). С другой стороны, ~~как было показано на примере Восточной Камчатки, а также можно видеть в районе вулкана Ньюберри [13] или в районе кальдерного комплекса Атитлан в Гватемале [21]~~, кроме отмеченной закономерности действует еще одна – и вулканические проявления и гидротермальная активность со временем смещаются в сторону фронта вулканической дуги: на Камчатке - к востоку, в районе вулкана Ньюберри [13] - к западу, а в Гватемале [21] - к юго-западу.

Приведенные данные, основанные на анализе геолого-структурной обстановки в районах развития современных гидротермальных систем позволяют уже на предварительном этапе изучения этих систем скорректировать направление разведочных и буровых работ и, по-видимому, существенно уменьшить их стоимость.

В заключение остановимся еще на одном аспекте, который необходимо учитывать при разведке геотермальных месторождений - на ~~это~~ возможное изменение ориентировки термовыводящих структур с глубиной. Изучение структурных условий локализации геотермальных месторождений на Камчатке позволило сделать вывод, что в период плиоцен-четвертичной тектоно-магматической активизации, в первую очередь, проявились в виде магмовыводящих структур наиболее глубоко проникающие разломы меридионального и широтного простирания. Позже, в среднем плейстоцене, активизировались движения по разломам северо-восточного простирания (глубина их проникновения составляла, по-видимому, около 10-15 км). В позднем плейстоцене-голоцене произошло заложение наиболее молодой сети разрывных нарушений, имеющих простирание ССВ 20-30°. Глубина их проникновения составляла сотни метров или первые километры [5]. Оценивая роль этих разломов, как магмо- термовыводящих структур, было сделано заключение, что обычно наиболее ярко проявленные на поверхности разломы северо-северо-восточного простирания (ССВ 20-30°) являются термовыводящими лишь в самых верхних этажах земной коры. При разведке глубоких частей месторождений они, по-видимому, должны иметь меньшее значение. При этом основной упор следует делать на выявление более древних разломов, которые в отдельных случаях могут не проявляться на поверхности и выступать как скрытые структуры. В глубоких частях месторождений их роль, как термовыводящих структур, может оказаться очень высокой.

Результаты изучения проницаемых зон Мутновского геотермального месторождения на Камчатке, полученные в последние годы, показали, что даже в пределах верхней разбуренной части месторождения движение потоков теплоносителя на разных уровнях осуществляется по разным каналам. В самых верхних этажах (первые сотни метров) простирание этих каналов преимущественно северо-северо-восточное (ССВ 20-30^{0}), а глубже - северо-восточное (СВ 45-50^{0}) [I]

Крупные разломы, активные на глубине, не всегда ясно проявлены на поверхности. В качестве примера можно привести субширотный Узонско-Валагинский разлом на Камчатке, который занимает секущее положение по отношению к основной магмоподводящей зоне Восточной Камчатки, имеющей северо-восточное простирание. Он плохо выражен на поверхности, но играет важную роль в глубинном контроле магматической деятельности в районе [5]. В узле пересечения этого разлома с основным магмовыводящим разломом в позднем плейстоцене сформировался сложный кальдерный центр и наиболее мощная на Камчатке гидротермальная система. К подобным структурам в США относится, по-видимому, линеамент Джеймз северо-восточного простирания, в узле пересечения которого с меридиональным рифтом Рио-Гранде сформировалась кальдера Вэллис. По мнению ряда исследователей эта структура является более значительным тектоническим элементом, чем рифт Рио-Гранде: рифт отражает верхне-коровое поле напряжений (до глубины 5 км), а линеамент Джеймз - нижне-коровое или мантийное поля [8, 24, 25]. Роль разломов северо-восточного простирания в этом районе была выявлена относительно недавно. Сделан вывод, что именно они вызвали многие отличия между предполагаемым и действительным состоянием структуры [22].

Подобная, не известная ранее скрытая зона разломов северо-восточного простирания (Дискавери) выявлена недавно и в районе кальдеры Лонг-Вэлли в Калифорнии. Эта зона образовалась до формирования кальдеры, а на посткальдерном этапе контролировала расположение экструзий и создавала в недрах этой структуры зоны высокой трещиноватости, вдоль которых происходила и происходит циркуляция гидротермальных растворов [27].

Переориентировка магмовыводящих каналов с глубиной явление, по-видимому, достаточно обычное. Так, изучение даек показало, что они часто вблизи поверхности расщепляются на сегменты, расположенные кулисообразно друг по отношению к другу. Это происходит из-за переориентировки полей напряжений на малых глубинах [II]. Наглядное подтверждение эти выводы получили при изучении куполов Инио в Калифорнии. Основная дайка здесь имеет длину около

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II км и простирание ССВ 7°, а вблизи поверхности она расщепляется на кулисообразно расположенные сегменты, которые имеют простирание СВ 15–25° [12]. Извержение вулкана Толбачик на Камчатке также показало, что основная питающая дайка на глубине имела здесь простирание СВ 20–22°, а ближе к поверхности простирание отдельных сегментов дайки изменялось на СВ 15–17° (под цепочкой конусов северного прорыва) и далее на СЗ 335–340° (под отдельными конусами как Северного, так и Южного прорыва) [2]. То есть, здесь также видно, что при приближении к поверхности магматическая колонна под каждым конусом, по-видимому, расщеплялась и разворачивалась на несколько десятков градусов.

Вопросы, которые были рассмотрены выше, несомненно, требуют дальнейшего изучения. Но все они – и типизация геотермальных районов на основе мощности земной коры и скорости ее растяжения, и закономерная миграция вулканической и гидротермальной деятельности в пространстве, и переориентировка магмо- и термоподводящих каналов с глубиной позволяют, по-видимому, уже сейчас более правильно оценить геотермальные ресурсы и вести разведку геотермальных месторождений с наименьшими затратами.

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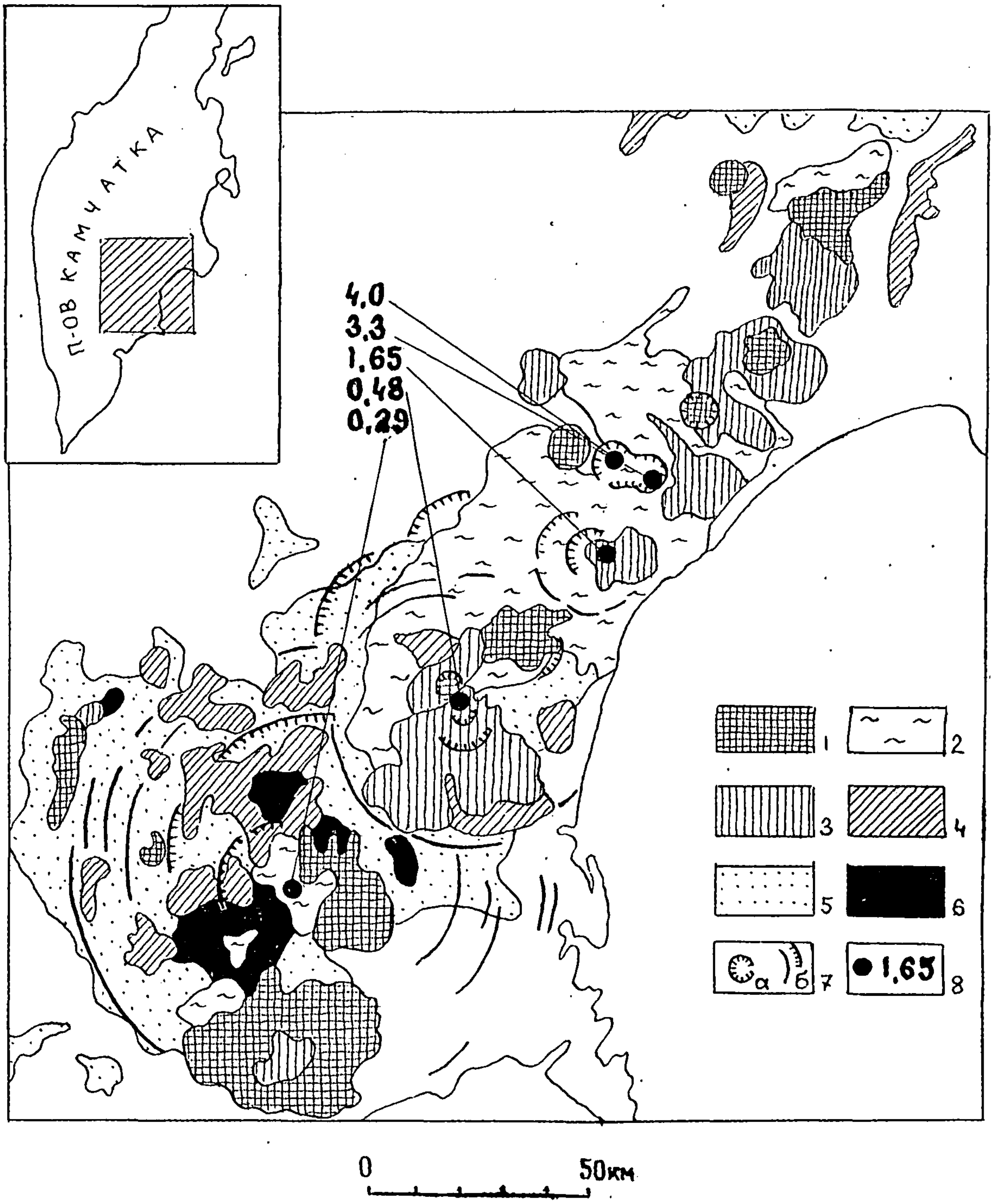
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4,0
3,3
1,65
0,48
0,29
1
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а
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1,65
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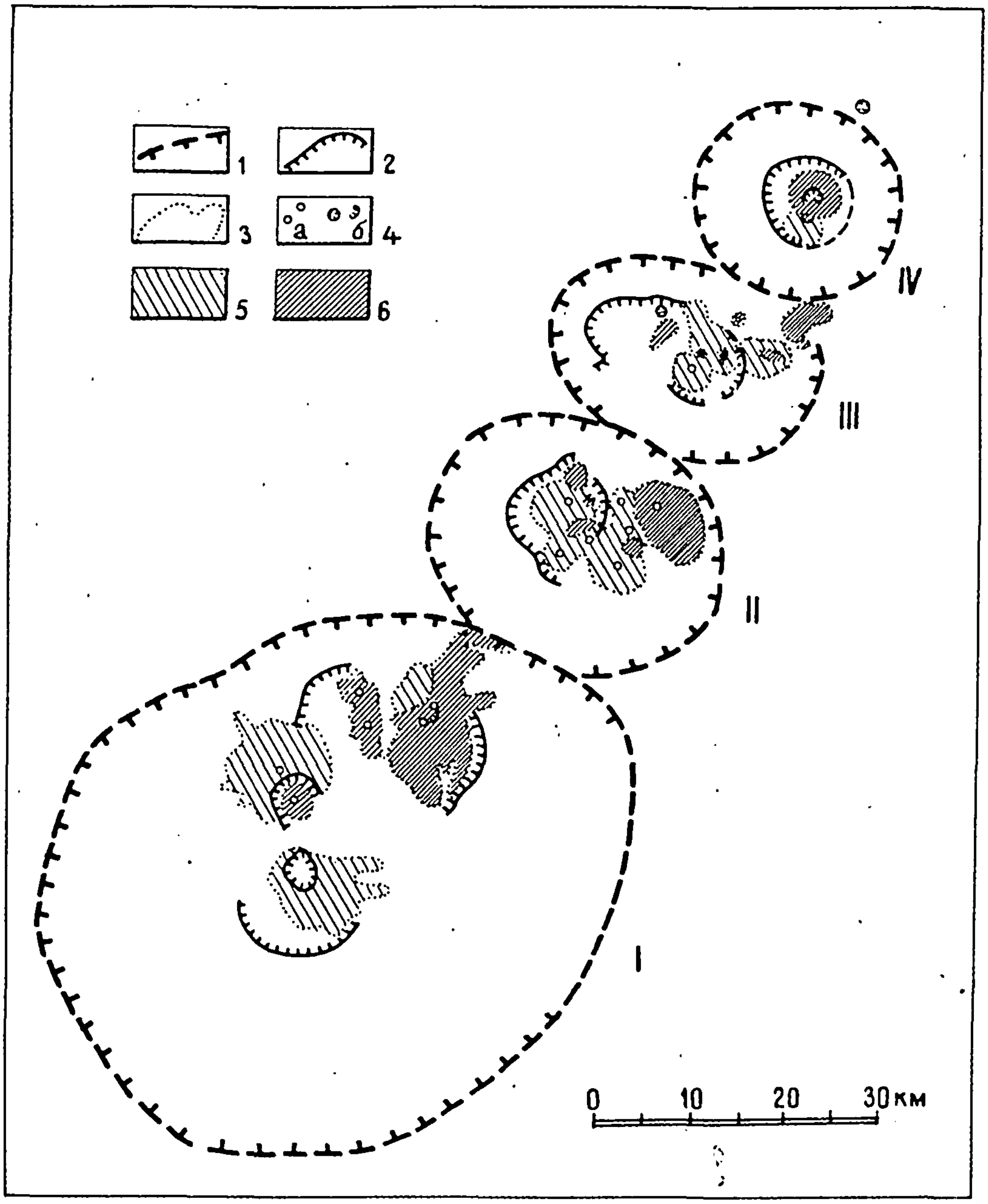
1
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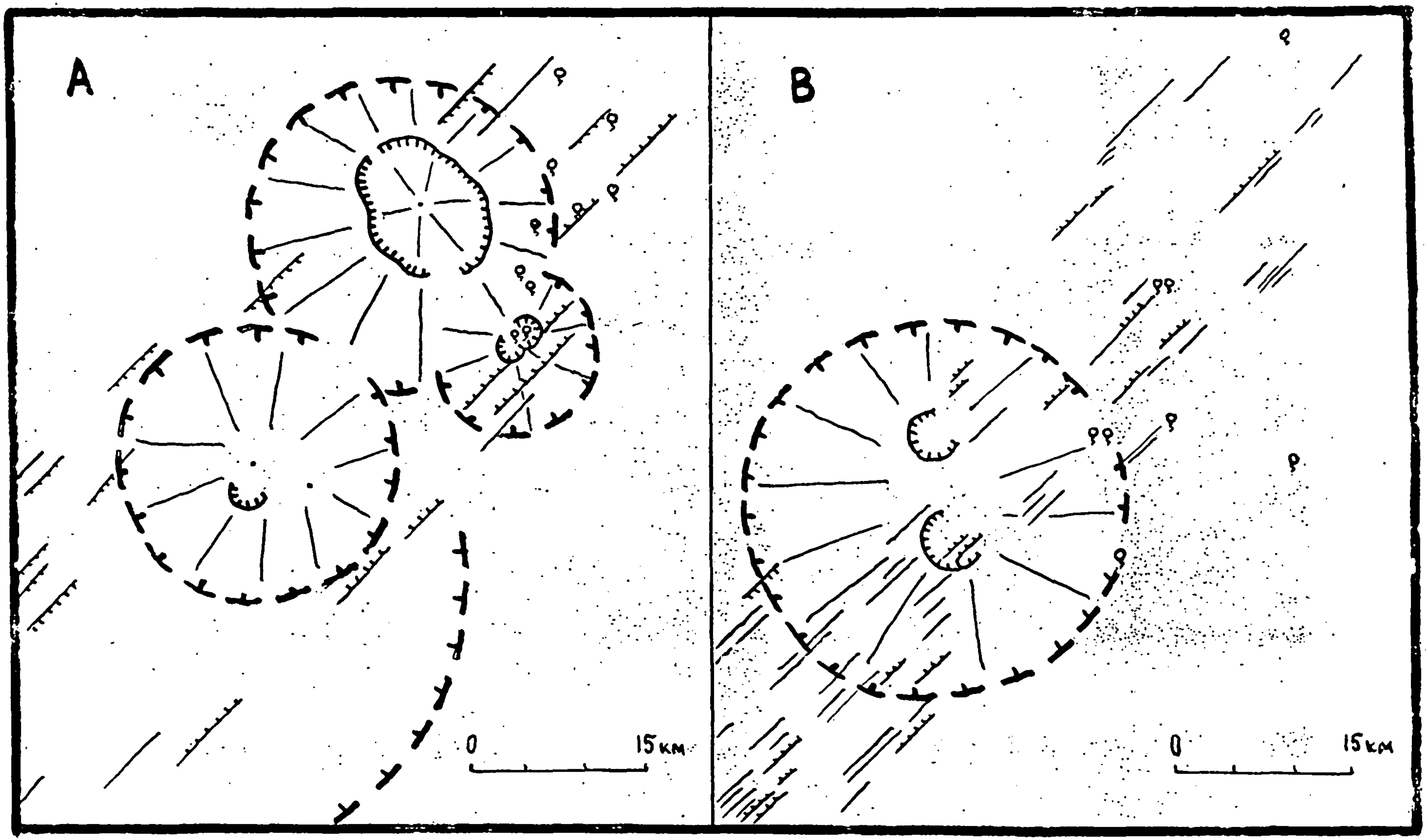
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Подрисуночные подписи

Рис. I. Области распространения вулканогенных пород плиоцен-четвертичного возраста на центральном участке Восточной Камчатки.

I-6 – области распространения пород: I – современных; 2 – средне-верхнечетвертичных (кислого состава); 3 – средне-верхнечетвертичных (основного и среднего состава); 4 – нижнечетвертичных; 5 – верхнемиоцен-плиоценовых; 6 – верхнепалеогеновых; 7 – кальдеры (а), дуговые разломы и зоны трещиноватости (б); 8 – гидротермальные системы и тепловая энергия, аккумулированная их горными породами (10^{18} кал).

Рис. 2. Вулканические центры центрального участка Восточной Камчатки.

I – Карымский, II – Больше-Семячикский, III – Узонско-Гейзерный, IУ – Крашенинникова.

I – предполагаемые границы вулканических центров; 2 – кальдеры; 3 – обобщенные контуры развития вулканических пород; 4 – центры вулканических построек (а), кратеры, маары (б); 5, 6 – площади, занятые посткальдерными вулканическими постройками ранней (5) и поздней (6) фаз.

Рис. 3. Схемы распространения термопроявлений в Мутновском и Киреунском геотермальных районах Камчатки.

Условные обозначения см. рис. 2.

Прямые линии (трещины) и линии с бергштрихами (сбросы) – трассируют глубинные зоны растяжения северо-восточного простирания.

1.3.2.Д.

14.1.А2 — 1.~~1~~3.2. ГЕОФИЗИЧЕСКИЕ МЕТОДЫ РАЗВЕДКИ ГЕОТЕРМАЛЬНЫХ РЕСУРСОВ

1.~~1~~3.2.1. Введение

Использование геотермальных ресурсов возможно в настоящее время прежде всего ввиде эксплуатации гидротермальных месторождений. Мировой опыт показывает, что при их разведке трещинно-жильный характер циркуляции термальных вод и мощный чехол четвертичных отложений затрудняют определение места заложения скважин. Детальные геофизические исследования способны существенно повысить эффективность разведочного бурения. В данном разделе проанализированы физические предпосылки применения геофизических методов при разведке гидротермальных месторождений, обоснован выбор рационального их комплексирования и приведены примеры их использования на гидротермальных месторождениях Камчатки.

В настоящее время на Камчатке известны 158 групп термопроявлений, среди которых около 100 имеют температуру свыше 60°С на глубине до 1500 м, а 17 – выше 90°С. Термальные источники приурочены преимущественно к Восточному и Центральному вулканическим поясам, к ранне-четвертичному вулканическому району Срединного хребта. На 13 термопроявлениях в разные годы были выполнены геофизические исследования. геофизиками Производственного геологического объединения "Камчатгеология" и коллективом лаборатории региональной геофизики Института вулканологии ДВО АН СССР

1.~~1~~3.2.2. Физические предпосылки применения геофизических методов при поиске и разведке геотермальных месторождений

При разведке месторождений термальных вод выбор комплекса геофизических методов должен базироваться на правильной оценке влияния термальных вод на физические свойства пород коллектора. Причиной их изменений могут быть в основном три фактора – температура, химический состав ~~активность~~ термальных вод и их количество. Кроме того, термальные воды влияют на величины геофизических аномалий в качестве самостоятельного геофизического объекта. Из опыта изучения термопроявлений Камчатки следует, что изменение пород под действием подземных ~~термальных~~ вод и особенно высоко термальных ~~температурных~~ происходит в зоне их циркуляции ~~термальных вод~~ ТВ и в маломощной приконтактовой зоне "сухих" пород. Поэтому аномалии геофизических полей, связанные с гидротермально измененными породами, приурочены либо к участкам современной миграции термальных вод, либо к участкам, где породы служили коллектором термальных вод в прошлом. Наиболее существенную зависимость от степени воздействия гидротерм проявляют свойства, определяющие электрические, магнитные и скоростные аномалии.

Магнитные свойства. Гидротермальное изменение пород, представленное серитизацией и окварцеванием, ведет к понижению магнитных свойств, так как при этом происходит разрушение магнетита. Вторичные кварциты, образующиеся при гидротермально метасоматическом изменении магматических пород, почти немагнитны, хотя первичные породы были магнитными. При взаимодействии кислых и слабокислых термальных вод с вмещающими породами происходит "обеление" пород с последующим образованием кварца вследствие избирательного выщелачивания железа из породообразующих минералов. Кроме того, происходит процесс "вымывания" железа из материнской породы термальными водами, уносящий до 70% железа из неизмененных пород [ ] . Следовательно, участки гидротермально измененных пород практически всегда выражаются пониженным магнитным полем, морфология которого зависит от конкретных геологических условий.

Удельное электрическое сопротивление. Электропроводность породы при обычных температурах определяется количеством присутствующей в ней воды, ее минерализацией и характером распределения в породе. При величине влагонасыщенности более 40% сопротивление породы начинает полностью отражать сопротивление раствора. На месторождениях термальных вод электрическая и химическая активность вод повышается под влиянием температуры. С повышением температуры сопротивление насыщающего породу раствора экспоненциально убывает [ ] . В еще большей степени удельное сопротивление термальной воды уменьшается по мере возрастания степени минерализации при любом солевом составе (изменение минерализации вод от 0,01 до 1 г/л может привести к изменению их удельного сопротивления в 100 раз). Очевидно, в районах гидротермальных месторождений минимальным сопротивлением обладают породы, насыщенные термальными минерализованными водами.

Скорость распространения упругих волн в горных породах. На гидротермальных месторождениях трещинно-жильного типа участки миграции термальных вод характеризуются сильно трещиноватыми породами, поэтому здесь можно ожидать аномально пониженные значения скоростей. Однако вопрос о соответствии участка с аномально низкой скоростью гидротермоподводящему каналу решается не однозначно и требует специальных исследований.

Плотности. ~~По зарубежным данным~~ С увеличением степени гидротермальных изменений значительно увеличивается плотность – на 0,3-0,4 г/см^3 по сравнению с неизмененными породами того же состава [9,10]. С другой стороны, имеются сведения, что вынос темноцветных компонент в процессе гидротермальных изменений приводит к уменьшению плотности пород. Привнос вещества из раствора несколько ее увеличивает. Конечный результат, видимо, зависит от длительности процесса и химического состава растворов.

Сделанный обзор показывает, что при гидротермальном изменении пород уменьшение значений физических параметров проявляется достаточно широко, но не имеет, однако, абсолютного характера.

I.3.2.3. Геофизические исследования на геотермальных месторождениях Камчатки

а. Опыт предшествовавших исследований

Использование геофизических методов для разведки месторождений термальных вод началось на Камчатке в конце 50-х годов на Паужетском и Налачевском геотермальных полях. В последующие годы был изучен ряд геотермальных месторождений юга Камчатки.

По условиям циркуляции вод В.И.Белоусов [2] выделил три основных типа гидротермальных систем. Паужетско-Вайракейский тип – высокотемпературный, с трещинно-поровыми условиями циркуляции; Паратунский тип – низкотемпературный, зоны разгрузки приурочены к крупным разрывным нарушениям или сводам, тип циркуляции трещинно-жильный, очаги разгрузки точечного характера; Кошелевский тип – современные гидротермальные системы вулканических построек.

Приведем примеры геофизических работ на месторождениях гидротермальных систем каждого типа. ~~(по данным сотрудников ПГО "Камчатгеология") И.М.Зайцева, Ю.А.Касабова, А.М.Осьмаковой, Я.Б.Шварца).~~

Больше-Банное месторождение высокотемпературных гидротерм расположено в грабеноподобной долине р.Банной. Преобладающая часть притоков термальных вод связана с зонами и трещинами, оперяющими основные разломы, а также приурочена к контактам даек и субвулканических тел с эффузивно-пирокластическими и эффузивными образованиями алпейской серии. Термальные воды относятся к сульфатно-хлоридно-натриевым термам с минерализацией I,2-I,6 г/л, максимальная температура, зафиксированная в скважинах, 167°С.

По магнитным данным отрицательными аномалиями ΔZ_a уверенно выделяются зоны разломов, подвергшиеся гидротермальному изменению. Разрез сопротивлений по данным ВЭЗ имеет сверху тонкий пласт высокого сопротивления (~ 1000 Ом.м.), затем мощный слой низкого сопротивления (до 10 Ом.м.), подстилаемый горизонтом "бесконечно" высокого сопротивления. Геологический разрез по данным бурения не соответствует этой схеме, следовательно основное влияние на величину сопротивления оказывает вода, ее минерализация и температура. В условиях узкой речной долины применение гравиразведки и сейсморазведки нецелесообразно. Результаты электро- и магниторазведочных работ оказались достаточно эффективными.

Кошелевское геотермальное месторождение располагается на склонах Кошелевского вулканического массива. Весь изученный разрез района представлен вулканитами андезито-базальтового состава, существенно измененными. В результате гидротермальной переработки все параметры физических свойств имеют пониженные абсолютные значения и широкий диапазон. Так, магнитная восприимчивость лав изменяется от 0 до 900×10^{-6} СГСМ, а плотность - от I,3 до 2,2 г/см^3. Установлены линейные отрицательные магнитные аномалии, связанные с протяженными тектоническими нарушениями и зонами измененных пород. По данным ВЭЗ на всей площади выделена толща пород с сопротивлением до 20 Ом.м, которая выходит на поверхность на участках современных термопроявлений. Успешно прошли опытные работы по непрерывному частотному зондированию. Все продуктивные скважины расположены в зонах низкого сопротивления (менее 20 Ом.м).

Паратунское низкотемпературное месторождение состоит из нескольких самостоятельных участков, расположенных в пределах структурной депрессии р.Паратунки. Термальные воды сульфатно-натриевые с минерализацией 0,9-2,2 г/л и максимальной температурой до

106°С. По данным магнито- и сейсморазведки хорошо выделяются интрузивные и экструзивные образования. По гравиметрическим данным фиксируются относительно поднятые и опущенные блоки фундамента и ортогональная система разломов, с местами пересечения которых связаны все участки поверхностных термопроявлений в долине реки Паратунки. Геоэлектрический разрез в основном трехслойный (рис. 1). Верхний слой мощностью 25-75м со средним удельным сопротивлением 200-300 Ом.м. охватывает аллювиальные и валунно-галечные отложения. Мощный (до 400м) горизонт пониженного сопротивления (10-40 Ом.м) соответствует алевролитам, конгломератам и верхней части коренных пород, обводненных термальными и смешанными водами. Опорный горизонт высокого сопротивления связан с мало-трещиноватыми коренными породами. Контуры зоны низких сопротивлений (<30 Ом.м) в общих чертах повторяют очертания высокотемпературной зоны (более 50°С). Полученные на Паратунском месторождении геофизические данные по геологическому строению и тектонике района хорошо согласуются с результатами бурения. По сейсмическим данным фиксируются тектонические нарушения, некоторые из них являются термовыводящими. Большинство продуктивных скважин расположено в зоне пониженного сопротивления.

Приведенные примеры свидетельствуют об эффективности применения геофизических методов при поиске и разведке месторождений термальных вод. По оценкам ~~геофизиков ПГО "Камчатгеология"~~, 33% скважин, заложенных по геофизическим данным, оказались продуктивными. Специфические черты геотермальных месторождений выявляются не всегда однозначно, поэтому совершенно необходимо применение комплекса геофизических методов.

6. Методика комплексных геофизических исследований

Опираясь на опыт геофизических работ на гидротермальных месторождениях мира и, в первую очередь, Камчатки, мы разработали методику исследований, которая была применена на Эссовском, Анавгайском и Пущинском геотермальных месторождениях [6]. Были выбраны методы и установлена последовательность их проведения. На первом этапе выполнялась площадная магнитная съемка, затем электроразведка методом ВЭЗ и сейсморазведка КМПВ. Такая последовательность работ была наиболее экономичной, так как знание площадного распределения магнитных аномалий позволило рационально выбирать систему наблюдений и необходимый объем более "тяжелых" методов.

Магнитная съемка на площади месторождений позволила выделить зоны гидротермально измененных пород, зоны тектонических нарушений и обнаружить интрузивные магнитные тела, перекрытые осадочным чехлом. Съемка выполнялась по сети профилей при расстоянии между ними 200м и между точками измерений – 50м. На участках высоких градиентов и перспективных на термальные воды (по комплексу методов) проводилась детализация по сети 10х10м. Точность съемки по повторным и контрольным пунктам была не хуже ±11,0нТл. Поскольку основную площадь съемки составляли плоские речные долины, поправки на рельеф не вводились.

Электроразведочные работы направлены на установление областей низкого сопротивления, соответствующих зонам гидротермальной переработки пород (первые десятки Ом.м) и зонам аккумуляции и разгрузки термальных вод (до единиц Ом.м). Использовалось в основном вертикальное электрическое зондирование по общепринятой методике. Величина разносов питающих линий составляла 1,5–2,0км, расстояние между пунктами ВЭЗ 0,2км. Узкие долины затрудняли выполнение крестовых расстановок. На Пущинском месторождении в опытном порядке выполнено индукционное частотное зондирование, по одной трассе получена зависимость кажущегося сопротивления от частоты, по другой – от расстояния между генгруппой и приемником. Индукционный метод позволяет получать информацию о больших глубинах при разносах, соизмеримых с ВЭЗ, и меньших физических затратах. Количественная интерпретация производилась палеточным способом.

Сейсморазведочные работы должны были определить структуру сейсмических границ (до глубин верхнемелового фундамента), выделить зоны трещиноватости, подверженные гидротермальному воздействию, и зоны разломов, перспективные на получение горячей воды.

На участках естественных выходов термальных вод были выполнены опытно-методические работы. Использовалась профильная система наблюдений КМПВ, включающая продольное и непродольное профилирование с шагом 50–100м. Для определения скоростных параметров верхней части разреза, уточнения положения разломов и их простирания был выбран шаг 10–20м. Всего на трех месторождениях выполнено 60км профилей, из них 15км отработаны с шагом наблюдений

I0-20м. Работы выполнялись с помощью сейсморазведочных станций типа "Поиск" - КМПВ, СМП-КМПВ. Взрывы мощностью от I до I0кг выполнялись в шпурах глубиной до 2м, а мощностью от I0 до 300кг - в специально подготовленных шурфах и котлованах, заполненных водой. Работы, выполненные на месторождении Эссо, где были пробурены заверочные скважины, позволили наметить несколько волновых признаков, характерных для зон концентрации гидротермальной деятельности. Основными являются разрывы корреляции при увеличении частот до 30 Гц; аномальное затухание сейсмических волн и резкое изменение кажущихся скоростей на коротких участках профиля.

в. Результаты комплексной геологической интерпретации геофизических данных на Эссовском месторождении термальных вод.

Эссовские и Анавгайские термопроявления относятся к единой Эссовско-Быстринской гидротермальной системе и приурочены к водонапорным гидрогеологическим структурам трещинно-жильного типа.

Сопоставление геофизических данных и результатов бурения позволило построить сводные геолого-геофизические разрезы Эссовского месторождения (рис. 2). По сейсмическим данным наиболее полно прослежена граница со скоростями 2,6-3,6 км/с, которая характеризует кровлю вулканогенно-осадочных образований алнейской серии. Глубина её залегания 30-I50м. Верхние кромки магнитоактивных тел имеют те же глубины, и некоторые осложнения рельефа кровли алпейской толщи представляют собой либо интрузивные либо экструзивные тела андезитового или риолитового состава (одна из андезитовых экструзий вскрыта скважиной I7 на глубине 30м). В разрезе сопротивлений соответствующая граница раздела отсутствует.

Верхняя часть разреза, характеризующаяся значениями скоростей 2,I-2,8 км/с, соответствует обводненной части толщи рыхлых четвертичных отложений. Верхняя сейсмическая граница (скорость 2,2-2,6 км/с) хорошо совпадает с нижней границей области высоких значений кажущегося сопротивления и указывает уровень залегания зеркала грунтовых вод на площади месторождения.

Нижняя сейсмическая граница отмечается только в северной части месторождения на глубине 500-720м, граничная скорость 4,0-4,6 км/с. Предположительно она относится к кровле верхнемелового-палеогенового фундамента.

Поскольку Эссовское месторождение относится к трещинно-жильному типу, максимальное внимание было уделено выделению тектонических нарушений разного порядка. По картам графиков вертикальной составляющей магнитного поля выделены предполагаемые зоны нарушений (рис. 3), ряд которых подтвержден сейсморазведочными данными. В зонах пересечения нарушений различного направления наиболее вероятно получение термальных вод, что подтверждается успешным бурением скважин I2, 20, 7, I6, I7 в пределах Центрального тектонического узла. Значительное количество нарушений связано с внедрением субпластовых и экструзивных тел. Они имеют разнообразную ориентировку и малую глубинность.

При выделении участков, перспективных на обнаружение термовыводящих зон, учитывался следующий комплекс признаков: а) линейные отрицательные магнитные аномалии; б) зоны низких сопротивлений, искаженные, неинтерпретируемые кривые ВЭЗ; в) зоны пониженных граничных скоростей; г) тектонические нарушения по геофизическим данным. Одним из первоочередных мест для заложения скважин был определен район профиля II магистрали I (рис. 3). Зона пониженных значений кажущихся сопротивлений (до 8 Ом.м.) имеет здесь минимальную глубину около I00м. Минимум магнитного поля и аномалия сопротивлений отражают скорее всего близповерхностные зоны растекания термальных вод. По магнитным и сейсмическим данным выделены разломы, уходящие на глубину около I00м. По второй сейсмической границе отмечается понижение граничной скорости до 2,6 км/с. Скважина I2, заложенная в точке пересечения выделенных разломов дала значительный водоприток с глубины около 600м при температуре воды на забое 74,5°C. Сходным сочетанием признаков обладают участки, выделенные в районе профиля I5 второй магистрали и профилей I2-I4 третьей магистрали. В пределах выделенных нами перспективных участков были пробурены 6 скважин, пять из которых (скважины I2,20,7,I6,I7) оказались высоко-продуктивными с температурой на глубине 72-77°C. Скважина I8 дала малый дебит при температуре 53,6°C на изливе, что связано, по-видимому, с тем, что она была заложена в стороне от тектонических нарушений, выделенных по геофизическим данным. Аналогичные результаты получены на Анавгайском и Пущинском месторождениях. Смещения скважин по технологическим причинам от указанных точек заложения в ряде случаев приводило к неудачам.

Таким образом, бурение на Эссовском месторождении показало правильность критериев выбора перспективных на термальную воду участков. Большое поисковое значение имеют зоны пониженных сопротивлений (менее 20 Ом.м.). Большинство скважин, вскрывших низкоомные зоны, имеют большой дебит самоизлива при высокой температуре воды (скважины I2,20,I6). Существенным оказалось размещение скважин вблизи или непосредственно на тектонических нарушениях, которые выделялись по сейсмическим и магниторазведочным данным. Косвенными признаками степени измененности пород служили интенсивность отрицательных магнитных аномалий и уменьшение скорости сейсмических волн. Все зоны, выделяемые в качестве перспективных, отличаются аномальными параметрами по всем изучаемым физическим свойствам.

I.4.2.4. Заключение

Использованный комплекс геофизических исследований геотермальных месторождений дал среднюю эффективность на трех месторождениях 60%. Работы, стоимость которых равна стоимости одной скважины, позволили задавать высокопродуктивные скважины с высокой вероятностью удачного результата. Естественно, что геофизические данные должны рассматриваться в сочетании с гидрогеологическими, геоморфологическими, структурными признаками, поскольку даже самый полный набор опробованных и проверенных критериев не дает полной гарантии успеха.

Выполненные геофизические исследования не имели целью выявление возможных источников нагрева вод. Однако, нам представляется правомерной точка зрения об участии в образовании гидротерм тепловых полей интрузивных камер и, возможно, периферических магматических очагов вулканов (для гидротерм на склонах активных вулканов, например, Кошелевского) [2,3]. Магматические очаги вулканов должны рассматриваться и как непосредственные источники геотермальной энергии, в связи с чем нами проводятся работы по изучению глубинного строения ряда активных вулканов Камчатки [1,5] .

ПОДРИСУНОЧНЫЕ ПОДПИСИ

Рис. 1 . Геолого-геофизический разрез по профилю I9 на Паратунском месторождении (по И.М.Зайцеву, 1969). а - Геологический разрез по скважинам I2-I0: I - песчаногалечные, гравийные отложения; 2 - туфы андезитов и андезито-базальтов; 3 - базальты; 4 - диоритовые порфириты; 5 - кварцевые диориты; 6 - алевролиты; 7 - андезиты; 8 - конгломераты; 9 - зоны дробления; I0 - разрывные нарушения. б - Геоэлектрический разрез и графики ΔZ и Δg : I - точки ВЭЗ; 2 - границы горизонтов сопротивления; 3 - преломляющие границы по данным КМПВ; 4 - тектонические нарушения по геофизическим данным; 5 - границы участков с различным удельным сопротивлением; 6 - линия абсцисс минимумов $\rho_к$ на кривых ВЭЗ. в - Разрез кажущихся сопротивлений

Рис. 2 . Сводные геолого-геофизические разрезы по профилям через скважины 6-I9(а) и I8-I5(б) Эссовского геотермального месторождения (из [63]). Заштрихованы области пониженного сопротивления, цифры у скважины означают дебит, температуру (в скобках) и минерализацию (в знаменателе) термальной воды. I - современные валунно-галечныковые речные отложения; 2 - верхнечетвертичные водноледниковые отложения; породы алпейской серии: 3-5 - туфы смешанного состава; 6 - крупно-обломочные андезито-базальтовые туфы; 7 - четвертичные экструзии и субпластовые тела; 8 - разломы, предполагаемые и вскрытые скважинами.

Рис. 3 . Схема разрывных нарушений Эссовского геотермального месторождения по геофизическим данным (из [61]). I - тектонические нарушения по магнито-разведочным данным; 2 - разломы по сейсмическим данным: а - неглубокого заложения, б- по основной преломляющей границе; 3 - зоны пониженных значений $\rho_к$; 4 - скважины; 5 - термальные источники

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1.3.2Ɗ

В.И.Кононов

~~14.1.13~~ ~~13.3.~~ Геохимические методы поисков геотермальных ресурсов

В последние десятилетия в областях современного вулканизма были проведены разносторонние геохимические исследования (Иванов, 1960, 1976; Набоко, 1974, 1980; Аверьев, 1964; Басков, Суриков, 1975,1990; Вакин, Сугробов, 1972; Кононов, 1983; Пампура, 1981, 1985; Таран, 1990; Эллис, 1965,1970; Arnorsson, Sigurdsson, 1982; D'Amore, Panichi, 1980; Craig, 1963; Giggenbach, 1980; Ellis, Mahon, 1977; Fournier, 1977; Fridleifsson, 1979; Henley, Ellis, 1983; Mahon, Mc Dowell, 1977; Lupton, 1976, Muffler, 1975; Nakamura, Sumi, Ozawa, 1977; Sigvaldason, 1966, 1979; Truesdell, 1975; Truesdell, Singers, 1974; White, Muffler, Truesdell, 1971; White, 1957, 1970, 1981 и др.), которые дали новые важные материалы, значительно расширевшие и во многом изменившие ранее существовавшие представления о распространении, составе и генезисе термальных вод. Полученные данные позволяют также выявить наиболее перспективные месторождения термальных вод и парогидротерм с помощью их химической типизации и определять глубинные температуры по геохимическим индикаторам.

~~13.3~~.1 Классификация терм по их химическому составу и температуре

Было установлено, что в зависимости от сочетания геологических, гидрогеологических, геохимических и геотермических условий формируются характерные типы термальных вод и парогидротерм. Эти типы выделяются нами прежде всего по их газовому составу и температуре, а для более дробного деления используются также анионный состав и величина минерализации (табл.). Их различия определяются пространственным положением гидротермальной системы относительно вулканического очага, условием ее теплового питания, первоначальным составом вод, пород, а также магматических эксгаляций и интенсивностью поступления последних в подземные воды.

В результате формируются различные типы терм, которые могут быть использованы для тех или иных практических целей.

Азотно-метановые и метановые хлоридные натриево-кальциевые термы с минерализацией до 25 г/кг и температурой около 50°С на глубине I км встречаются во многих районах Тихоокеанской, Средиземноморской и Восточно-Африканской провинций. Они развиты в артезианских бассейнах межгорных впадин и формируются обычно вне сферы активного воздействия вулканических процессов. К этому типу относятся, например, широко известные метановые и азотно-метановые воды Японии, вскрытые в миоцен-плиоценовых отложениях впадин Акито и Канто на о.Хонсю, а также имеющие аналогичный состав термальные воды Мексики распространенные в кайнозойских отложениях, обрамляющих Калифорнийский и Мексиканский заливы. В континентальных и межконтинентальных рифтовых зонах с чехлом осадочных пород, содержащих эвопориты, при внедрении манматических очагов в артезианские бассейны с метановыми водами образуются необычные метановые парогидротермы с минерализацией 200 г/кг и повышенным содержанием рудных компонентов (например, некоторые гидротермальные системы рифтовых зон Калифорнийского залива и Восточной Африки).

Азотные щелочные (pH 8-I0), маломинерализованные (< I,5 г/л) термы с температурой на выходе ниже точки кипения, а на глубине менее I50°С распространены преимущественно в гидрогеологических массивах за пределами районов современного вулканизма. Общий вынос тепла в очагах их разгрузки имеет порядок 10^6 кал/с. Газонасыщение этих вод низкое, газ почти целиком (95-99% об) состоит из азота. Термы имеют переходные значения Eh от I0 до I60 мВ. Месторождения азотных терм формируются в зонах дробления магматических и метаморфических пород разного возраста. Например, в Исландии (Рис1) эти термы приурочены к глубинным разломам в миоцен - нижнеплиоценовых платобазальтах (источники района Рейкъявика и др.). Термы этого типа ис-

используются для теплоснабжения домов и теплиц, а также для бассейнов.

Углекислые гидротермы (до 75°С) различного ионного состава, с минерализацией обычно менее 10 г/л распространены в районах с затухающей вулканической деятельностью и/или интенсивным развитием на глубине термометаморфических процессов. Они характеризуются субнейтральной реакцией (pH 6-8) и значениями Eh от 0 до 250 мВ. Среди углекислых терм наиболее часто встречаются гидрокарбонатные натриевые (характерным их примером в Исландии являются источники Лисуходль); менее распространены сульфатные углекислые термы (например, источники Витербо в Италии) и хлоридные термы (Налычевские источники на Камчатке и др.). Термы этого типа широко используются в курортном деле.

Углекислые и азотно-углекислые низкоминерализованные парогидротермы с различным составом и температурой 200-350°С формируются в сфере влияния активных вулканических очагов в зонах тектонических нарушений. В зависимости от соотношения водного и теплового питания они подразделяются на гидротермальные системы с преобладанием воды или пара.

Азотно-углекислые парогидротермы формируются в зонах глубоких тектонических нарушений в восстановительных условиях. Они все относятся к системам с преобладанием воды и разгружаются на дневной поверхности в виде высокодебитных кипящих источников и гейзеров. Содержание газов в них обычно не превышает 50-100 мл/л. В рифтовых зонах Исландии (рис.1) парогидротермы такого типа имеют гидрокарбонатный или сульфатный натриевый состав с минерализацией менее 2,5 г/л и pH = 9 (Большой Гейзер, Аурхвер).

В районах современного вулканизма островных дуг наиболее характерными являются азотно-углекислые парогидротермы, преимущественно хлоридного натриевого состава с минерализацией 1-6 г/л (например, Долина Гейзеров и Паужетка на Камчатке и др.).

Углекислые парогидротермы образуют гидротермальные системы как с преобладанием пара, так и с преобладанием воды. В месторождениях с преобладанием пара (Лардерелло и Монте Амиата в Италии, Нижне-Кошелевские на Камчатке, Кавах-Камоджанг в Индонезии и др.) минерализация флюидов обычно ниже I г/л, а конденсат пара имеет гидрокарбонатный или сульфатный натриевый состав при почти полном отсутствии хлоридов. В месторождениях с преобладанием воды (Бродлендс, Каверау, Вайракей в Новой Зеландии, Лос Умерос, Ла Примавера в Мексике и др.) парогидротермы, как правило, имеют хлоридный натриевый состав, а их минерализация повышается до 5 г/л.

Общий вынос тепла в очагах разгрузки углекислых и азотно-углекислых парогидротерм составляет 10^7 кал/с. Они могут применяться для всех видов использования, но чаще на месторождениях этого типа строят ГеоТЭС.

Сероводородно-углекислые термы приурочены к активным вулканическим аппаратам. Они образуются в окислительных условиях в местах поступления в подземные и поверхностные воды фумарольных и сольфатарных газов (H_2S, CO_2, HCI, HF, SO_2 и т.п.) и последующего взаимодействия сильнокислых (pH $<$ I) растворов с вулканическими породами. Температура парогазовых струй в кратерах активных вулканов достигает иногда 700°C, а температура фумарольных источников ниже или равна точке кипения. Сероводородно-углекислые термы делятся на два характерных подтипа:

I) поверхностного формирования - кислые (Eh от -300 до 0 мВ) сульфатные со сложным катионным составом и минерализацией до 20 г/л;

2) глубинного формирования - кислые и ультракислые (Eh от -350 до 600 мВ) хлоридные (хлоридно-сульфатные) со сложным катионным составом (с Fe, AI, H и др.) и минерализацией до 35 г/л.

Углекисло-водородные ("водородные") парогидротермы (до 350°C) приурочены к океаническим рифтам. Они формируются под влиянием мантийных расплавов и высокотемпературных вулканических эманаций. В их газовом составе в значительном, а иногда господствующем количестве присутствует H_2 (кроме того, в них содержатся CO_2, H_2S, N_2 и другие газы). "Водородные" термы, заключенные в базальтах океанической коры в подводных условиях, представляют собой, в основном, нагретые морские воды. В надводной же части рифта в Исландской Срединной неовулканической зоне (рис.I)это - маломинерализованные (< I г/л) растворы, отличающиеся повышенным содержанием кремнезема и отсутствием в анионном составе хлора. В конденсатах этих струй обычно ведущую роль играют SO_4, HCO_3, Na . При выходе на дневную поверхность термы этого типа характеризуются низкими значениями Eh (от -300 до 0 мВ) и слабощелочной реакцией. Гидротермальные системы с преобладанием H_2 в составе газов (Несьяведлир, Наумафьядль, Крабла в Исландии, Гейзеры Санома в США и др.) отличаются наиболее высоким тепловым потенциалом (до 10^8 кал/с) и температурой на глубине несколько сот метров до $350^{\circ}C$. Поэтому они разгружаются на поверхности Земли в виде мощных газопароводяных струй.

Тепловая мощность месторождений этого типа позволяет строительство здесь крупных ГеоТЭС.

Специфическая группа береговых терм встречается на побережьях морей (или минерализованных озер), где иногда создаются условия для поступления современных морских (или озерных) вод в находящиеся в береговой зоне гидротермальные системы. Такие береговые термы различаются по своему газовому составу, но их ионно-солевой состав довольно однообразен. На морских побережьях он хлоридный натриево-кальциевый с минерализацией обычно до 35г/кг или несколько выше (например, гидротермальные системы Рейкьянес и Исафьордур в Исландии и Горячий Пляж на о.Кунашир).

Источниками тепла современных гидротерм являются во всех случаях региональное тепловое поле, а в особенно мощных гидротермальных системах еще и локализованный тепломассопоток из мантии. Тепловые параметры азотных, углекислых и метановых гидротерм согласуются с моделью нагрева этих вод в фоновом геотемпературном поле в пределах верхних 2-2,5 км разреза, вмещающих их гидрогеологических структур. Тепловая же мощность высокотемперутурных водородных, метановых, сероводородно-углекислых и азотно-углекислых парогидротерм, как показывают расчеты, (Кононов, 1983), не может быть обеспечена только за счет съема подземными водами фонового кондуктивного теплопотока. В этих случаях, по-видимому, имеет место либо поступление в гидротермальную систему высокоэнтальпийного глубинного флюида, либо ее дополнительный кондуктивный прогрев от неглубоко залегающих магматических очагов.

Главными источниками воды современных гидротермальных систем являются инфильтрующиеся вглубь атмосферные осадки, но в некоторых системах преобладают воды морского генезиса. По современным представлениям доля магматического флюида в водном балансе наиболее мощных гидротермальных систем обычно не больше 5-10%.

Основная часть растворенных в воде веществ заимствуется из вмещающих пород либо поступает в гидротермальную систему вместе с седиментогенными и современными морскими водами. Аномально большие концентрации рудных элементов, обнаруженные в термальных рассолах Солтон Си и в некоторых термах океанического дна (Красноморский и Галапагосский рифт, термопроявление на 21° с.ш. 109° з.д.), также, по нашему мнению, связаны прежде всего с выщелачиванием вмещающих пород высокоминерализованными хлоридными натриево-кальциевыми рассолами в условиях высоких температур. Главными факторами, определяющими характер и масштаб гизогидротермальной деятельности являются геологическое строение и состав пород, гидрогеологические особенности гидротермальной системы, существующие в ней P-T условия, состав, температура и давление глубинных магматических эксгаляций и интенсивность их поступления в подзёмные воды.

Среди процессов, формирующих состав термальных вод специфическими для районов современного вулканизма являются процессы, связанные с фазовыми переходами подземных вод. Такие фазовые превращения гидротерм наблюдаются обычно в приповерхностной зоне очагов их разгрузки, где происходит вскипание и дегазация высокотемпературных вод. При этом компоненты химического состава терм перераспределяются повсеместно. Это прежде всего процессы, формирующие поступление вещества в раствор (газонасыщение вод, выщелачивание и растворение вмещающих пород).

Таким образом, в областях современного вулканизма, отличающихся типом земной коры и интенсивностью проявлений геотермальной активности под воздействием перечисленных выше факторов и процессов одновременно и независимо друг от друга формируются специфические термальные флюиды, существенно различающиеся по составу содержащихся в них газов, растворенных солей, величине pH и Eh, общей минерализации и тепловым параметрам. Изучение общего анализа и, в особенности, газового состава гидротерм сразу может дать ответ на перспективы их использования. Так, например, термы с азотным составом газов обладают слишком низким для строительства ГеоТЭС тепловым потенциалом. Наоборот, присутствие в составе газа в заметных количествах водорода указывает обычно на высокие тепловые параметры данной гидротермальной системы. Более точно определить глубинные температуры можно с помощью гидрохимических геотермометров.

Высокая минерализация или повышенная кислотность термальных растворов, содержание в них ценных или вредных компонентов указывают на необходимость правильного выбора технических средств по ~~увели~~изучению и использованию подобных терм. ~~Анализируя химический состав и температуру источников можно заранее определить пригодность данных гидротерм для того или иного вида использования.~~

I.3.3.2 Геохимические индикаторы глубинных температур

Гидрохимический метод определения глубинных температур в гидротермальных ситемах получил большое распространение. Сущность метода заключается в расчете температуры продуктивного горизонта по данным химического опробования поверхностных термопроявлений. Рассматриваемый метод в ряде случаев позволяет без поискового бурения выявить наиболее перспективные участки гидротермального месторождения. Успешное применение указанного метода определяется правильным выбором гидрохимического индикатора. Геотермометры могут быть разделены на ионные, газовые и изотопные, а также нейтральных ионных пар (слабодиссоциированных соединений). К ним относятся: содержание растворенного кремнезема; величины Na/K атомных и ионных отношений; $Na/K/Ca$ - мольное отношение, изотопные отношения δD, δO^{18}, δC^{13}.

Корреляционная связь между температурой и тем или иным геотермометром установлена экспериментально и натурными наблюдениями. На показания геотермометров оказывают влияние физические и химические факторы. К первым относятся температура, давление, скорость потока гидротерм, время существования системы и др. Ко вторым - минералогический и химический состав пород, парциальные давления газов, pH,и др. Искажающее влияние физических факторов в оценке температуры можно свести к минимому, используя величины отношений компонентов применительно к гидрохимическим геотермометрам. Сложнее учесть воздействие химических факторов. Здесь в каждом отдельном случае должна вводиться поправка, установленная при натурных наблюдениях или экспериментально. О надежности того или иного геотермометра можно судить, сравнивая рассчитанные по нему температуры с измеренным в скважинах уже изученных месторождений термальных вод.

Количественная оценка глубинных температур с помощью геотермометров производится по следующим формулам.

I. Расчет по силикатермометру в интервале температур от 0 до 250° (при SiO_2 мг/H_2O кг) по формулам Р.Фурнье (Fournier , 1977)

по аморфному кремнезему $$t^{\circ}C = \frac{731}{4,52-\lg C} - 273,15 \qquad (I)$$

β -кристобалиту $t^oC = \dfrac{781}{4,51 - \lg C} - 273,15$ (2)

α -кристобалиту $t^oC = \dfrac{1000}{4,78 - \lg C} - 273,15$ (3)

халцедону $t^oC = \dfrac{1032}{4,69 - \lg C} - 273,15$ (4)

$t^oC = \dfrac{1112}{4,91 - \lg SiO_2} - 273,15$ * (4a)

кварцу (при кондуктивном охлаждении раствора)

$t^oC = \dfrac{1309}{5,19 - \lg C} - 273,15$ (5)

кварцу (при адиабатическом охлаждении раствора)

$t^oC = \dfrac{1522}{5,75 - \lg C} - 273,15$ (6)

II. Расчет по Na /K-термометру (мг/л) в интервале температур 100-245°C по формуле Д.Уайта и А.Эллиса (White , 1970)

$t^oC = \dfrac{855,6}{\lg Na/K + 0,8573} - 273,15$ (7)

по формуле Р.Фурнье и А.Трусделла (Fournier, Truesdell , 1973)

$t^oC = \dfrac{777}{\lg Na/K + 0,70} - 273,15$ (8)

по формуле С.Арнерсона и Е.Гунлаугсона (1983) в интервале температур 25-250°C

$t^oC = \dfrac{933}{0,993 + \lg Na/K} - 273,15$ (8a)

Ш. Расчет по Na/K/Ca-термометру (моль/л)

по формуле Р.Фурнье и А.Трусделла (Fournier, Truesdell , 1974)

$t^oC = \dfrac{1647}{\lg(Na/K) + \lg(Ca/Na) + 2,24} - 273,15$ (9)

* По формуле С.Арнерсона и Е.Гунлаугсона (1983) в интервале температур от 25 до 180°C

при $\beta = 4/3$; $\sqrt{Ca/Na} > I$; $t < I00^\circ C$;

при $\beta = I/3$; $\sqrt{Ca/Na} < I$; $t > I00^\circ C$.

Т.Пачес (Pačes , I975) обнаружил систематическое отклонение измеренных температур от рассчитанных по формуле (9) в тех случаях, когда температура источника ниже $70^\circ C$ и парциальное давление CO_2 более $I0^{-4}$ атм. Им предложен поправочный коэффициент $I = -I,36 - 0,254 \cdot P_{CO_2}$, с учетом которого эта формула примет вид (Truesdell, I976)

$$t^\circ C = \frac{1647}{\lg Na/K + 4/3 \lg(\sqrt{Ca/Na}) + 3,6 + 0,253 P_{CO_2}} - 273,15 \qquad (10)$$

Применение той или иной формулы зависит от температуры, газонасыщенности и дебита исследуемых источников. Выбор наиболее подходящей формулы производится по следующей схеме:

I. Кипящие источники	Расчет ведется по формуле
I. с низким дебитом (<3 л/сек)	
с низким газовым фактором (<0,06%)	(4)
с высоким газовым фактором (>0,06%)	(5)
2. с высоким дебитом (>3 л/сек)	
с низким газовым фактором	(6)
с высоким газовым фактором	(5), (7), (8), (9) или(I0)
П. Некипящие источники	
I. с низким дебитом	
с низким газовым фактором	(7),(8)
с высоким газовым фактором	(I),(2),(3) и (9)(при I00°
2. с высоким дебитом	
с низким газовым фактором	(9)
с высоким газовым фактором	(7),(8)

Обычно охлаждение гидротерм по пути их движения к очагу разгрузки происходит вследствие смешения вод, резко отличающихся по температуре, или же в результате их медленного кондуктивного охлаждения. В первом случае для выбора менее разбавленного холодными водами источника применяется хлоркарбонатное отношение (оно будет выше в менее разбавленных водах), а оценку температуры проводят по формулам (5) и (6), беря среднюю. Во втором случае температуру оценивают по формуле (5).

Прогноз температур с помощью геотермометров для низкотемпературных малодебитных вод наименее точен, поскольку будет сказываться влияние всех факторов, приводящих к охлаждению раствора. При этом желательно привлечение других признаков, указывающих на температуру. Так, например, наличие гейзерита вокруг источника может служить свидетельством высоких температур недр в настоящее время или в недалеком прошлом. Присутствие же травертина указывает на сравнительно низкие глубинные температуры. Однако точную картину получить трудно. Поэтому при проведении геохимического опробования всегда следует стараться брать пробы воды из наиболее высокотемпературных и высокодебитных источников.

Предполагая, что газы в пластовых условиях полностью растворены в воде, можно перейти от парциальных давлений к концентрациям в молях на кг воды и предложить следующие геотермометры (Таран, 1988):

CO_2-геотермометр (x; в моль/кг)

$$\lg X_{CO_2} = 5{,}94 - 4036/T, \quad r = 0{,}85,$$

где r – коэффициент корреляции;

H_2S-геотермометр

$$\lg X_{H_2S} = 5{,}85 - 4568/T, \quad r = 0{,}92,$$

H_2-геотермометр

$$\lg X_{H_2} = 6{,}51 - 5156/T, \quad r = 0{,}87.$$

Для исландских гидротерм H_2-геотермометр имеет несколько иной вид

$$\lg X_{H_2} = 5{,}31 - 4723/T, \quad r = 0{,}93.$$

Довольно сложную комбинацию концентраций всех главных компонентов геотермальных газов (кроме азотных) предлагают Д.Аморе и Панике

(1980):

$$t^oC = 24447 / (\alpha + \beta - 36),$$

где $a = 2\lg\frac{CH_4}{CO_2} - 6\lg\frac{H_2}{CO_2} - 3\lg\frac{H_2S}{CO_2}$ концентрации в об.%;

$$\beta = 7 - \lg P_{CO_2}$$

Как было установлено (Поляк и др., 1979) изотопный состав гелия в формирующейся и зрелой коре коррелирует с плотностью кондуктивного теплового потока. Поэтому появилась возможность его вычисления по изотопно-гелиевым данным по следующей формуле:

$q = 0{,}166 \ln R + 3{,}95 \pm 0{,}03$, где

$R = {}^3He/{}^4He$.

На основании найденной закономерной связи можно предварительно оценивать величину глубинного теплового потока в неразбуренных районах.

DRAFT

FOCUS ON

THAILAND

A GEOTHERMAL INTERNATIONAL SERIES

SPONSORED BY:

U.S. DEPARTMENT OF ENERGY
GEOTHERMAL TECHNOLOGY DIVISION (GTD)

PREPARED FOR:

LOS ALAMOS NATIONAL LABORATORY
UNDER CONTRACT NO. 9-X36-3652C

PREPARED BY:

MERIDIAN CORPORATION
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PREFACE

The *Focus on* Series is prepared to give the U.S. Geothermal Industry a quick profile of several foreign countries. The countries depicted were chosen for both their promising geothermal resources and for their various stages of geothermal development, which can translate into opportunities for the U.S. geothermal industry. The series presents condensed statistics and information regarding each country's population, economic growth and energy balance with special emphasis on the country's geothermal resources, stage of geothermal development and most recent activities or key players in geothermal development. The series also offers an extensive list of references and key contacts, both in the U.S. and in the target country, which can be used to obtain detailed information.

The series is available for the following countries:
Argentina, Azores (Portugal), China, Costa Rica, Ecuador, El Salvador, Ethiopia, Guatemala, Honduras, Indonesia, Jordan, Mexico, St. Lucia, Thailand.

Additional countries might be available in the future.

The series is to be used in conjunction with four other publications specifically designed to assist the U.S. geothermal industry in identifying and taking advantage of geothermal activities and opportunities abroad, namely:

- The *"Review of International Geothermal Activities and Assessment of U.S. Industry Opportunities."* Final Report, August 1987. Prepared for Los Alamos National Laboratory.

- The *"Summary Report"* of the above publication.

- *"Equipment and Services for Worldwide Applications,"* U.S. Department of Energy.

- The *"Listing of U.S. Companies that Supply Goods and Services for Geothermal Explorers, Developers and Producers Internationally,"* August 1987, prepared by GRC.

Copies of these publications can be obtained from the Geothermal Technology Division of the U.S. Department of Energy. Correspondence should be addressed to:

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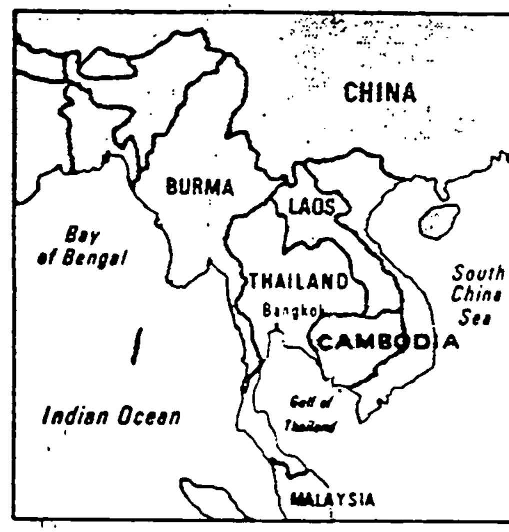
FOCUS ON THAILAND



Official Name: Kingdom of Thailand

Area: 514,000 sq. km (198,500 sq. mi.)

Capital: Bangkok

Population (1985): 51.7 million

Population Growth Rate: 2.0%

Languages: Thai, ethnic and regional dialects

Economic Indicators:

Real GNP (1985): $42 billion
Real Annual Growth Rate (1985): 6%
Per Capita Income (1985): $828
Avg. Inflation Rate (1985): 8%

Trade and Balance of Payments:

(1985) Exports: $9.771 million; Major Markets: Japan, EC, U.S., Singapore
(1985) Imports: $11,325 million; Major Suppliers: Japan, EC, U.S.

(1985) Official Exchange Rate: 27.5 baht = US $1

Energy Profile: (Based on 1982 data unless otherwise indicated)

- Commercial Fuel Energy Consumption:

  Total: 12.926 million ton of oil equivalent (mtoe)
  1-Yr. Growth: 6.5%

- Commercial Fuel Breakdown:

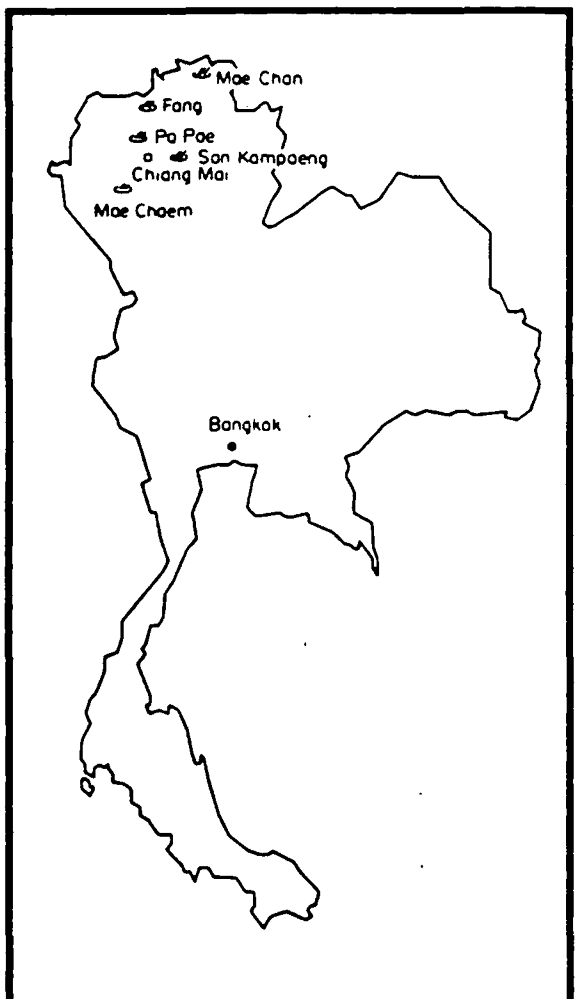
  Liquid Fuels Pct: 93%
  Solid Fuel Pct: 3%
  Natural Gas Pct: *
  Electric Pct: 4%
  Commercial Fuel Consumption Growth Rate (1970-1980): 82%

* Negligible

GEOTHERMAL RESOURCES

The Agency for International Development (AID) and the United Nations Development Program (UNDP) have financially aided programs aimed at geothermal development in Thailand. AID has supported a program financing development of renewable energy alternatives, including geothermal, while the United Nations has helped fund a geothermal reconnaissance survey of northern Thailand. A total of 60 hot spring areas have been mapped throughout Thailand as part of the Geothermal Exploration Project, Department of Mineral Resources of Thailand. The ultimate power potential may be 150 MW for 30 years. Surface temperature ranges from 40 to 100°C.

Assessments of Thailand's geothermal potential were started in late 1977. At the time, San Kamphaeng geothermal field, located northeast of Chiang Mai, was chosen for exploration drilling because of its favorable geology and geographic location. The evaluation was carried out by the Department of Mineral Resources, Chiang Mai University, and the Electricity Generating



Location of the promising geothermal areas in Thailand

Source: S. Praserdvigai, 1986, "Geothermal Development in Thailand." Geothermics, Volume 15, No. 5/6.

REFERENCES

AND

KEY CONTACTS

B. Geothermal-Related Sources of Information

The following reports and documents are suggested for further information regarding geothermal energy and export opportunities overseas:

Los Alamos National Laboratory:

- Review of International Geothermal Activities and Assessment of U.S. Industry Opportunities

U.S. Department of Energy

- Equipment and Services for Worldwide Applications
- Guide to the International Development and Funding Institutions for the U.S. Renewable Energy Industry
- Federal Export Assistance Programs Applicable to the U.S. Renewable Energy Industry
- International Data Base for the U.S. Renewable Energy Industry
- Committee on Renewable Energy Commerce and Trade: CORECT's Second Year - October 1985-November 1986

California Energy Commission (CEC)

- Foreign Geothermal Energy Market Analysis
- Small Scale Electric Systems Using Geothermal Energy: A Guide to Development

U.S. Department of Commerce - International Trade Administration

- A Competitive Assessment of the U.S. Renewable Energy Equipment Industry

U.S. Export Council for Renewable Energy

- International Renewable Energy Industry Trade Policy

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Geothermics, Vol. 19, No. 2, pp. 151–185, 1990.
Printed in Great Britain.

p154

0375-6505/90 $3.00 + 0.00
Pergamon Press plc
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THE THERMAL AND GEOCHEMICAL STRUCTURE OF THE BROADLANDS–OHAAKI GEOTHERMAL SYSTEM, NEW ZEALAND

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(*Received April 1989; accepted for publication September 1989*)

Abstract—Fifty two wells have been drilled into the Broadlands–Ohaaki geothermal system, New Zealand, in the course of its development. Fluid samples collected from these wells and measured temperatures indicate that boiling is common within the East and West Bank production zones, separated at the surface by the Waikato River. Steam-heated waters form over the top of the system, above zones of boiling, and are also present on the margins of the system. They are CO_2-rich, and are responsible for dilution of the deep chloride fluids, particularly on the margins of the system. Thermal inversions are common on the margins of the system, associated with the steam-heated waters. The eastern portion of the East Bank and margins of the West Bank have cooled since peak thermal conditions, possibly due to dilution, as indicated by comparing fluid inclusion data with temperatures now present. However, fluid inclusion Th and Tm data indicate that boiling and dilution patterns similar to those now present have existed since inclusion formation. The hydrothermal alteration of the silicic volcanics comprises an assemblage of quartz–albite–illite–adularia–calcite–chlorite–pyrite; epitode and wairakite are rare, and pyrrhotite, sphalerite and galena are generally confined to the margins of the system. Kaolin, Ca-montmorillonite, cristobalite and siderite are also present on the margins of the system to depths of 600–1200 m, and are related to the presence of the CO_2-rich, steam-heated waters. The deep production fluids originate from a parent (preboiled) fluid with a temperature of ~300°C and a CO_2 content of ~0.6 mol. Excess enthalpy (i.e. two phase feed zone) discharges are not suitable for the calculation of activity ratios in the reservoir liquid and assessment of mineral–fluid equilibria; this is probably due to non-equilibrium distribution of gas species between liquid and vapor. However, an assessment of mineral–fluid equilibria is possible from the compositions of liquid feed wells. Based on these data, the reservoir fluids are now slightly undersaturated with respect to calcite and are in equilibrium with K-mica, pyrite and chlorite. The common presence of adularia and calcite in veins and open spaces may be due to a shift in mineral–fluid equilibria caused by extensive boiling and gas loss in fractures as compared to formation fluid. In contrast, the marginal steam-heated waters are in equilibrium with pyrite–pyrrhotite. Their lower pH values make them more undersaturated with respect to calcite and K-feldspar than the chloride fluids, due mainly to the lower temperatures and concentration of CO_2, resulting in interstratified illite–smectite and even kaolinite ± siderite stability. Dilution and cooling of the boiling fluids by the steam-heated waters has caused their shift to K-mica stability; the resulting deposition of illite in fractures of the East Bank may be responsible for the lower permeabilities here, causing excess enthalpy conditions.

Steam-heated waters are common in geothermal systems throughout the world; recognition of dilution patterns helps in deducing the overall geochemical structure of each system. Knowledge of the distribution of steam-heated waters will also assist in locating upflow zones, and also allows their potential for casing corrosion and production-induced incursion to be assessed.

INTRODUCTION

A large data base has been accumulated for the Broadlands–Ohaaki geothermal system, New Zealand (Fig. 1), in the course of its exploration and development as an energy source. The large number of wells (52) drilled in and adjacent to the system (Fig. 2) has allowed a detailed examination of natural thermal and chemical variations present prior to sustained discharge testing. Previous studies have not had access to the present data base nor have they fully

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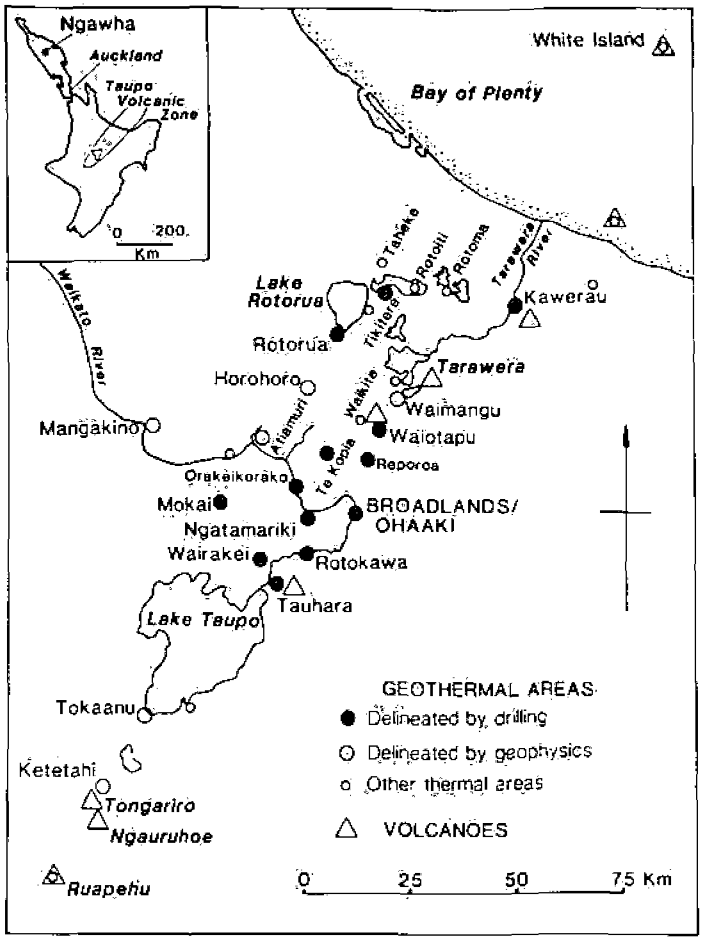

Fig. 1. Map of the Taupo volcanic zone, New Zealand, showing the location of the Broadlands–Ohaaki geothermal system among its many neighbors.

integrated all constraining evidence into a model of the system. In particular, the importance of the marginal steam-heated waters on the overall nature of the system has not been discussed by earlier workers. This paper presents a model of the geochemical structure of the natural state of the geothermal system. This has been deduced from thermal profiles and all available chemical and isotopic data available prior to extensive testing of the system. In addition, thermal and chemical data from fluid inclusion studies provide an indication of the natural evolution of the Broadlands system (Ohaaki refers to the power station).

Ideally, the chemical composition and distribution of fluids in the system will be in equilibrium with the alteration minerals; where disequilibrium is apparent (as at nearby Waiotapu; Hedenquist and Browne, 1989), it may be possible to deduce the spatial and temporal evolution of the fluid. The general approach outlined by Giggenbach (1980, 1981, 1984, 1988) in assessing geothermal mineral–fluid equilibria has been used here, with the alteration mineralogy framework from Browne (1971a, 1973a), Browne and Ellis (1970) and Wood (1983). This basic approach to mineral–fluid equilibria, in addition to the geochemical model of the system, serves as the framework for a detailed examination of mineral chemistry and local disequilibrium discussed elsewhere (Lonker *et al.*, in press).

In general, the purpose of this paper is to clarify and add detail to our understanding of the processes operating in the upper 2000 m or so of a volcanic-hosted hydrothermal system in a low relief terrane, particularly with respect to boiling and mixing, which are the two dominant physical processes in geothermal systems (Giggenbach and Stewart, 1982). This will help in interpreting geothermal systems for which there are fewer data, or systems at an early stage of exploration, particularly in terms of the presence and effects of marginal waters. The relatively simple model derived here may also constrain any detailed computational approach involving

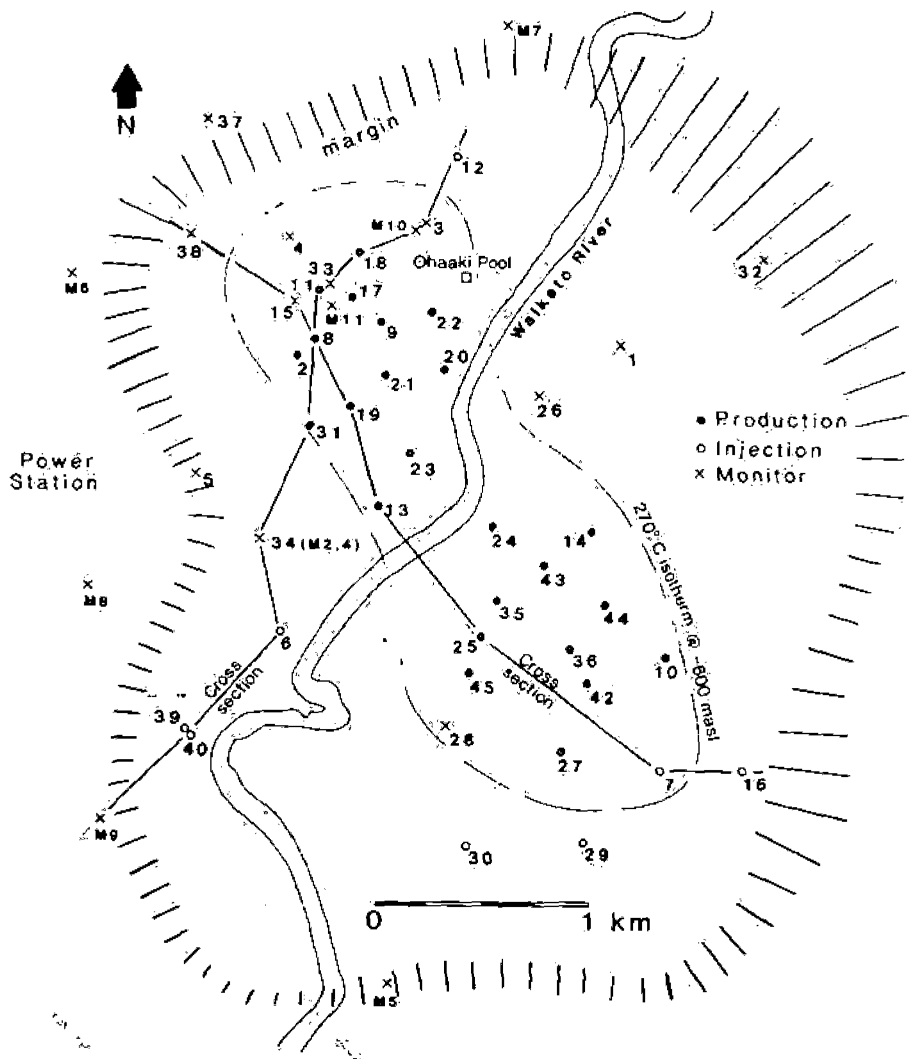

Fig. 2. Plan of the Broadlands–Ohaaki system showing the location of production, injection and monitor wells drilled between 1965 and 1984. The resistivity margin (Risk, 1986) and 270°C isotherm at ~900 m depth (−600 m a.s.l.) are also shown.

reaction progress and mass transfer (Reed, 1982; Giggenbach, 1984; Spycher and Reed, 1989) developed for hydrothermal systems and related epithermal mineralization.

Background and previous studies

There are few surface thermal features at Broadlands, and the total natural heat flow is ~100 MW (Allis, 1980). This is small compared to about 500 MW at the nearby Wairakei and Waiotapu systems, due to a large subsurface outflow. The principal thermal feature is Ohaaki Pool (Fig. 2), a neutral pH chloride hot spring, which contributes about 10 MW to the total surface heat flow from the system. A few warm springs on the banks of the Waikato River, and some steaming ground between wells BR7 and 29, make up the surface activity, with subsurface seepage also contributing to the surface heat flow. However, the hydrothermal system is extensive at several hundred meters depth, as defined by electrical resistivity traversing (Risk, 1986) and drilling. The <10 Ωm apparent resistivity anomaly (500 m electrode spacing) is about 10 km^2 in area and roughly circular in shape (Fig. 2). The production wells all lie within the 270°C isotherm at −600 m a.s.l. (~900 m depth). This high temperature anomaly is elongate north northwest–south southeast, and is about 3 km^2 in size; the Waikato River bisects both anomalies into East and West Banks.

Exploration drilling began in late 1965, and by 1984, 52 wells from 366 m (BR33) to 2587 m (BR34) deep were drilled, including several shallow (150 to 350 m deep) monitor wells (Fig. 2); most wells are between 1000 and 1500 m deep. The depths of the feed zones of production wells range from 470 to 1450 m (mainly 800 to 1000 m), and have measured temperatures of 260 ± 20°C.

Following long term discharge testing between 1968 and 1971, at least 100 MW was proven. However, the decision to construct a power station was deferred until the early 1980s due to the discovery of natural gas fields off the west coast of the North Island.

A 116 MW(e) power station was commissioned in 1989, using steam at 13.5 and 4.5 bars absolute from 24 production wells, collected at five separation plants. The separated water at 4.5 bars is reinjected into eight wells along the southeast to southwest margin of the system (Fig. 2). The abnormally long lead-in time has resulted in a large amount of information being gathered about the system, largely in a natural to slightly disturbed state. Over this period, many detailed studies of the system were conducted.

The alteration mineralogy and mineral–fluid equilibria of the Broadlands system were first discussed in detail by Browne and Ellis (1970) in a landmark paper on geothermal systems. Preliminary observations on the fluid chemistry were made by Mahon and Finlayson (1972), while Giggenbach (1971) determined the effect of boiling on the isotopic composition of production well discharges. Mahon *et al.* (1980) noted the presence of steam-heated "bicarbonate" waters at Broadlands, and Hedenquist and Stewart (1985) quantified their chemistry, distribution and importance in the overall geochemical structure of the system; these steam-heated waters are CO_2-rich and very corrosive to grout and well casing. Predicted production-related chemical changes in the reservoir have been discussed by Hedenquist *et al.* (1988).

Further mineralogical studies at Broadlands were conducted by Eslinger and Savin (1973); along with Blattner (1975), they focused on the details of oxygen isotope variations in the hydrothermal system. Sulfide sulfur isotopes have been characterized by Browne *et al.* (1975), while Browne *et al.* (1976) reported the first extensive fluid inclusion study of a geothermal system. These and other geochemical studies are summarized by Hedenquist (1986).

Gold-rich precipitates deposited in Ohaaki Pool from about 1957 to 1966, associated with an epithermal suite of elements including silver, arsenic, antimony, mercury and thallium (Weissberg, 1969). In addition, base metal sulfides are common at depth (Browne, 1969), and have been the subject of much detailed study (Browne, 1971b; Browne and Lovering, 1973; Ewers and Keays, 1977). These results have been reviewed by Weissberg *et al.* (1979) and Browne (1986). The metal transporting capability of the deep Broadlands fluids was elucidated by Brown (1986), who demonstrated unequivocally the analogy of this active system to the environment of epithermal mineralization.

GEOLOGY AND STRATIGRAPHY

The Broadlands–Ohaaki geothermal system lies near the eastern fault margin of the Taupo Volcanic Zone, which comprises a principal andesitic arc and, further west, a marginal basin. The area has experienced volcanic and tectonic (mainly rifting) activity for at least one million years (Cole, 1979, 1984). The voluminous calc–alkaline rhyolitic eruptions have caused caldera subsidence and resulted in the formation of variably welded pyroclastic flows. These flows and their reworked (lacustrine) equivalents, plus airfall tuffs and pumice breccias, dominate the stratigraphy, overlying the block-faulted Mesozoic greywacke basement.

Recent airfall deposits dominate the surface geology at Broadlands, due to the low relief (300 m a.s.l. at the Waikato River to a maximum in the area of 350 m a.s.l. at the power station on the west margin of the system). The subsurface geology is known mainly from the study of drillcore and cuttings (Grindley and Browne, 1968; Browne, 1971a, 1973a; Wood, 1983). In addition to the flat lying pyroclastic flow and airfall deposits, there are several interbedded (laterally discontinuous) rhyolite and dacite flows; intrusive bodies have not been identified. The volcanics rest uncomformably on the greywacke and argillite basement, as shown in the southeast–northwest cross-section (Fig. 3: *approximately at a right angle to the dominant north northeast structural trend in the region*).

There is a large amount of relief on the basement surface due to faulting (at least 800 m between BR7 and BR15, 3 km distant); however, this faulting does not extend appreciably into the overlying volcanics as most are laterally continuous (Figs 3 and 4). A map of basement elevation (Fig. 5) shows a horst block centered on a line between BR29 and BR10; the basement surface deepens abruptly to the west. Permeability in the basement is confined to fractures related to the faults. However, permeability in the overlying volcanics appears to be concentrated along formation contacts (C. P. Wood, personal communication, 1988), as well as within some units with aquifer characteristics (e.g. the Rautawiri Breccia; Browne and Ellis, 1970). Wan and Hedenquist (1981) suggested that northwest trending structures may explain the elongation of the thermal anomaly in that direction (Fig. 2).

Shallow rhyolite flows are variably permeable; locally they act as aquifers to steam-heated waters and adjacent cold groundwater. A section through West Bank wells (Fig. 4) shows the extensive nature of the shallow Ohaaki Rhyolite flow; the flow is distinct (both in mineralogy and hydrologic continuity) from the Broadlands Rhyolite flow in the southwest.

ALTERATION MINERALOGY

The silicic host rocks of the Broadlands system originally contained an assemblage of quartz and andesine phenocrysts set in a glassy to fine grained groundmass. Minor amounts of hornblende, biotite, hypersthene, magnetite, ilmenite, apatite and zircon were also present (Browne and Ellis, 1970; Browne, 1973a). Quartz and apatite have been little affected by the hydrothermal alteration, whereas the other primary minerals have reacted to a varying degree depending largely on the temperature and permeability (i.e. fluid flux; Browne, 1978). Primary minerals are little affected where the temperatures are low (on the margins of the system) or where there is poor permeability resulting in little fluid flow (despite high temperatures, e.g. in some of the dense rhyolite flows and welded ignimbrites). In contrast, the highly porous and

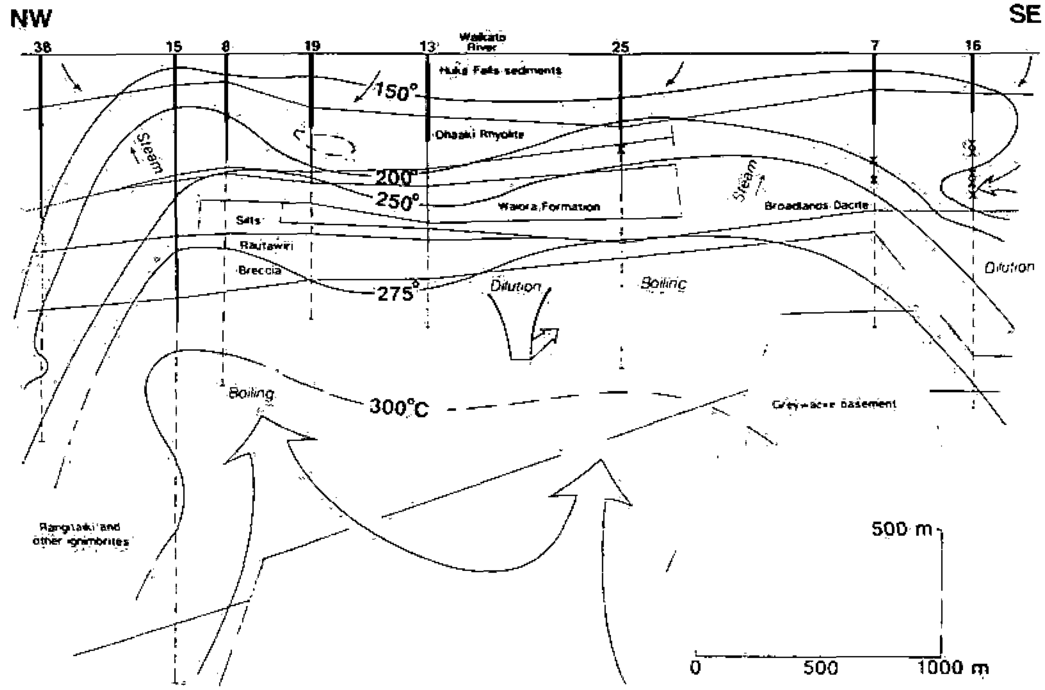

Fig. 3. Northwest–southeast cross-section through the Broadlands system showing stratigraphy (Browne, 1971a; Wood, 1983) and isotherms (initial measurements after post-drilling stabilization; Ministry of Works and Development, 1977), and the inferred (schematic) distribution of CO_2-rich, steam-heated waters (stippled), as well as general patterns of boiling and dilution. Boiling conditions prevail across most of the base of the system from at least 300°C, where the isotherm is near horizontal, and continue to the near surface in the two zones of upflow. The steam-heated waters form over the top of the system and then may drain to deeper levels on the margins due to their relatively cool temperature and higher density. The position of extreme (external) casing corrosion (Hedenquist and Stewart, 1985), marked on BR7, 16 and 25 casing, and some of the thermal inversions, help constrain the distribution of the steam-heated waters. Modified from Hedenquist and Stewart (1985).

permeable Waiora and Rautawiri Breccia Formations are generally completely altered. Fluid composition and, to a lesser extent, rock composition, are also factors affecting hydrothermal mineralogy (Browne, 1978).

The principal hydrothermal mineral assemblage at 260°C (600–800 m depth) is quartz–albite–illite–adularia–calcite–chlorite–pyrite. Epidote and wairakite are rare due to the relatively high P_{CO_2} (Browne and Ellis, 1970). Calcite is a common and abundant mineral, present in core from all wells. It forms as a replacement mineral and also occurs as a groundmass and fracture filling. Quartz is one of the most abundant minerals, both as coarsely crystalline fracture filling (to 2 cm), as well as a fine grained product (including cristobalite at lower temperatures) of groundmass devitrification (Browne and Ellis, 1970). Kaolin (including dickite), Ca-montmorillonite, interstratified illite–smectite, cristobalite, siderite, leucoxene and mordenite occur in the cooler, marginal portions of the system.

The mineral assemblages discussed here are consistent with present temperatures (to a maximum of 305°C; Browne and Ellis, 1970). Where present, the phyllosilicate minerals are good semiquantitative indicators of temperature and fluid composition (Browne, 1978; Wood, 1983). Montmorillonite typically forms at temperatures below about 140°C and illite is usually restricted to temperatures above 230°C; interstratified illite–smectite, with a 001 basal spacing between 10 and 15 Å, forms at intermediate temperatures. The presence of kaolinite indicates

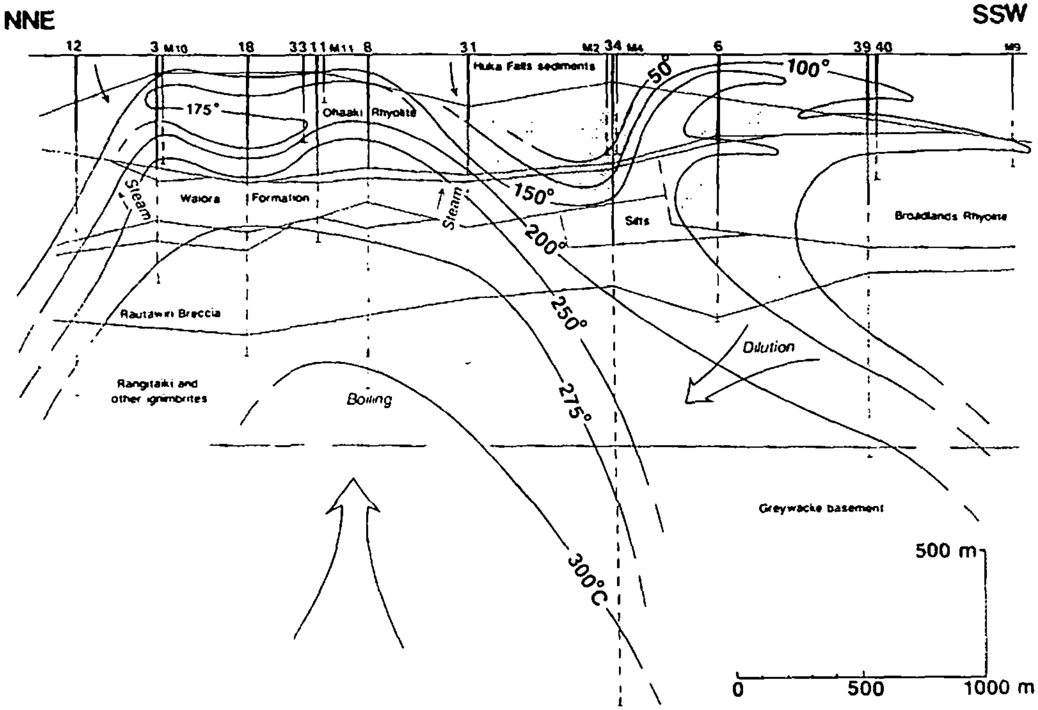

Fig. 4. North northeast–south southwest cross-section through West Bank wells, showing the same information as Fig. 3. The extensive presence of steam-heated waters on the southwest margin of the system is confirmed by the composition of downhole samples of BR6, 39 and 40 (Table 5). This section is essentially parallel to the dominant structural trend (and direction of fracture permeability?) in the Broadlands system.

hydrolysis due to a depressed pH, whereas montmorillonite or illite indicates less acid conditions.

The distribution of the interstratified illite–smectite clays, as well as kaolinite and siderite, is summarized in Table 1 (data from the detailed compilations of alteration logs by Browne, 1971a and Wood, 1983). These minerals indicate relatively low temperatures and/or less than neutral pH values; these mineral occurrences will later be compared with the distribution of the CO_2-rich, steam-heated groundwaters.

The overall pattern of interstratified illite–smectite distribution is simple, and reflects their position in the system, i.e. upflow or marginal (Figs 3 and 4). Interstratified illite–smectite is the dominant alteration at shallow (100–300 m) levels; it is not present below depths of 200 to 400 m over the West Bank upflow (e.g. in wells BR2, 9, 11, 17 and 18; Browne, 1971a; Wood, 1983). In contrast, illite–smectite is present to 300–500 m depth in the East Bank production zone (e.g. BR25, 27, 28). The depths of illite–smectite occurrences increase to 400 to 650 m towards the margins (e.g. BR7, 10, 12, 13, 14, 19, 23, 24, 26, 30, 31 and 34). At the cool margins (Figs 3 and 4), illite–smectite is present to depths of 800 to 1400 m (e.g. BR5, 32, 37, 38 and 39).

Kaolinite is not particularly common at shallow levels, in contrast to most other New Zealand systems, due to the scarcity of surficial acid sulfate, steam-heated groundwaters. However, kaolinite is present at depths of 400–960 m (Table 1) on the margins of the system (BR6, 12, 31, 32, 37, 38 and 39); this also contrasts with other New Zealand systems, where kaolinite is generally restricted to the surficial 50–100 m (Hedenquist, 1986). Siderite is a common mineral at shallow levels (Table 1), but occurs at a greater depth on the margins (100–200 m in BR10, 13, 14, 19, 20 and 22; to 400–800 m in BR6, 12, 23, 27, 30, 31, 34, 37, 38, 39 and 40). Pyrrhotite is

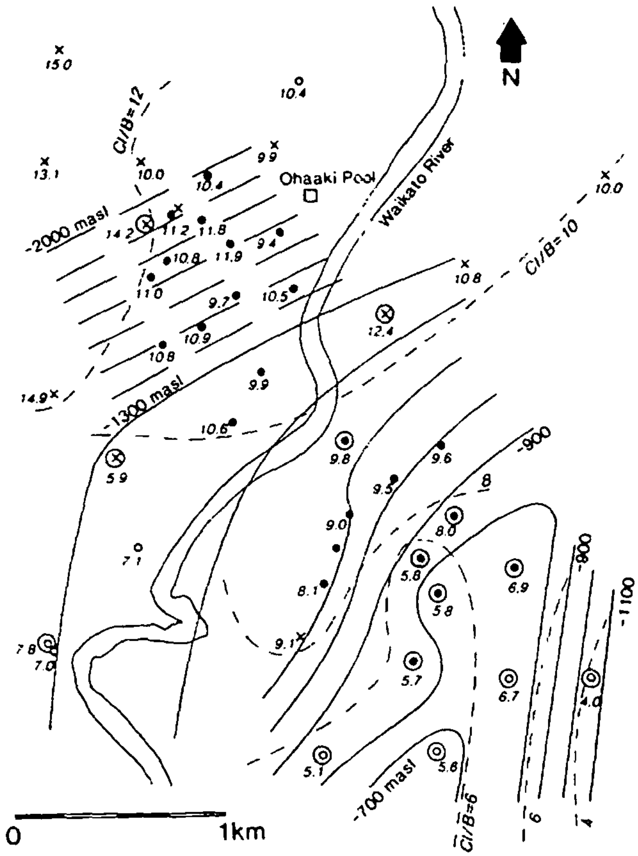

Fig. 5. Map showing the elevation (in m a.s.l.) of the top of the Mesozoic greywacke basement (data from Browne, 1971a; Wood, 1983); wells which penetrate basement are circled. There is a close inverse correlation between depth to basement (local elevation ~300 m a.s.l.) and the Cl/B ratio, with discharges from wells in the vicinity of the horst block (southeast) having the lowest Cl/B values (Table 3). This may be due to boron being fixed in alteration minerals forming in the volcanics, once the fluids leave the dominantly fracture-controlled permeability of the basement, or to a direct magmatic input of B in the East Bank (Giggenbach, 1989b).

irregular in its distribution, but is more common in marginal wells (BR1, 4, 5, 7, 12, 13, 14, 15, 16, 27, 34 and 39).

The base metal sulfides, particularly sphalerite and galena, are locally abundant (e.g. BR16; Browne, 1969, 1971b; Ewers and Keays, 1977). They are most common in the easternmost portion of the system (BR7, 10, 14, 16, 27, 29 and 42; Browne, 1986), though there are minor occurrences in cores from BR15 (at deep levels) and BR17 on the West Bank.

THERMAL STRUCTURE

Direct measurements

The thermal structure of Broadlands is well known from the 52 wells drilled. The total discharge testing of these wells, equivalent over the past 20 years to about two and a half years of the planned production for the 116 MW station, means that the thermal structure has not yet been greatly disturbed. The temperatures used to construct the isotherms of Figs 3 and 4 were measured shortly after drilling, subsequent to thermal reequilibration (the formation is cooled during drilling). Careful interpretation of the profiles during the post-drilling heating provides information on formation permeability and the locations of cool inflows as well as temperature. These measurements were conducted prior to bleeding the well, which often causes two-phase conditions to develop; later development of internal circulation also masks the predrilling temperature, particularly by eliminating temperature inversions.

Figure 6 shows temperature profiles measured for several wells shortly after post-drilling thermal recovery. These illustrate a variety of situations, most notably boiling profiles (e.g. BR9, 15, 22 and 25), thermal inversions (e.g. BR6, 16, 23, 32, 38 and 39) and lower temperatures on the margin of the system (e.g. BR12 and 31). The boiling profiles are shifted from that of pure water (Haas, 1971) due to the P_{CO_2} contribution to the total pressure (Sutton and McNabb, 1977; Hedenquist and Henley, 1985).

Boiling curves have been modelled by Sutton and McNabb (1977), who calculated that the

Table 1. Distribution of interstratified illite–smectite, kaolinite and siderite (from Browne, 1971a and Wood, 1983)

Well	Deepest I/S (m)	Kaolinite (m)	Siderite (m)
1			
2	120		
3			
4	380		
5	820		
6	797	679–764	720–800
7	500		
8			
9	380		
10	650		75
11	400		
12	620	400–610	100–600
13	520		100–350
14	550		166
15			
16	478	150 (dickite)	
17	300		
18	300		
19	650		100–180
20	680		100
21			
22			
23	500		420
24	600		
25	360		160
26	560		
27	400		
28	310		
29	464	150, 230	
30	627		630
31	610	92, 503	330, 700, 1096
32	915	610, 740	
33	198		
34	600		101, 378, 512, 600
35			
36			
37	>1370	860, 960	347 960
38	1160	400	630, 670
39	945	835	630, 736
40	>360		460

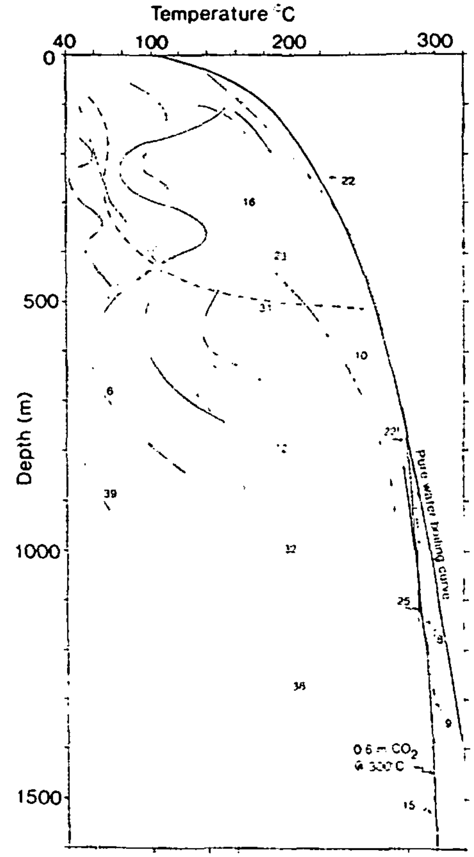

Fig. 6. Initial thermal profiles (after post-drilling stabilization) of several wells showing boiling relationships (for pure water and a liquid containing ~0.6 mol CO_2), temperature inversions or marginal conductive gradients (e.g. BR12). Most shown here (except for BR9, 15, 22 and 25) do not have boiling profiles, as they are on the margins of the system. Most production wells have boiling profiles, though they have not been shown to reduce the clutter. Some production well profiles have a temperature inversion in the midst of a typical boiling curve (e.g. BR10). From Ministry of Works and Development (1977).

deviation from pure water was due to the presence of ~4 wt% (0.9 mol) CO_2 in the initial 300°C fluid. A value of 0.6 mol (2.6 wt%) CO_2 at 300°C (deduced from an interpretation of measured CO_2 concentrations, discussed below) has been used to construct a model boiling profile on Fig. 6. This curve closely approximates the typical thermal profiles present in the upflow portions of the system.

The profiles which show major thermal inversions are for wells on the margin of the system, and indicate a lateral flow of cooler waters (either as incursions into or outflow from the system, e.g. BR6, 16, 32, 38 and 39). Some of the production wells in the East and West Bank upflow zones have shallow (200–400 m deep) inversions (cased off), indicating shallow incursion of relatively cool waters over the top of the system as well as on its margins (e.g. BR3, 18, 19 and 33; Figs 3, 4 and 6). These inversions are caused by steam-heated water whose chemical composition and distribution are discussed below.

Overall, deep chloride fluids of the two production zones ascend along a boiling temperature profile, adjusted for the CO_2 content of the water (constantly decreasing as it fractionates to the steam phase). The two principal zones of upflow, centered on the East and West Bank production zones (Fig. 3), are separated by a zone of lower temperatures beneath the Waikato

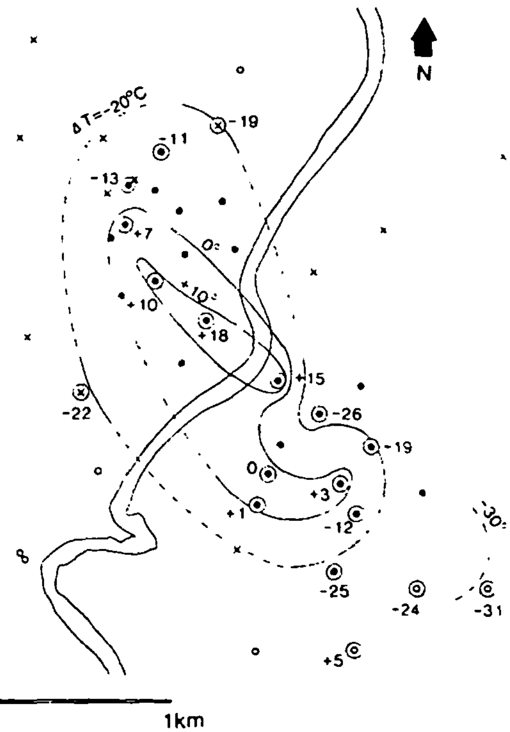

Fig. 7. Comparison of past (primary fluid inclusion homogenization, except for BR34) with present (measured) temperatures (ΔT, Table 2). The eastern portion of the East Bank and the margins of the West Bank have cooled considerably, probably due to dilution, since peak thermal conditions.

River. The vapor (steam plus gases) that forms from the boiling fluid ascends and mostly condenses into and heats cold groundwater (or cooled chloride water) over the top of the boiling fluid. This latter situation can be deduced from the relative paucity of surface thermal features at Broadlands (Allis, 1980), despite the common occurrence of boiling (Fig. 6).

Most of the upflow of the Broadlands system mixes with steam-heated waters on the margins of the system and outflows laterally in the subsurface, subsequently being entrained by groundwater; little deep fluid (~10%) rises to the surface. After eventually joining the groundwater, much of the upflow/outflow probably reaches the Waikato River downstream.

Deductions from fluid inclusion thermometry

Several fluid inclusion studies incorporating homogenization (Th) and ice melting (Tm) measurements have been conducted on Broadlands minerals, mainly quartz but also some calcite and minor sphalerite (Browne *et al.*, 1976; Browne and Christie, personal communication, 1982; Hedenquist and Henley, 1985; Hedenquist, unpublished data). Browne *et al.* (1976) concluded that the fluid inclusions formed at temperatures similar to those now existing. However, upon closer examination of a larger data set for mainly quartz (Table 2), some systematic trends may be observed (Fig. 7).

Obviously necked inclusions have been avoided in these studies. Wide ranges in Th for primary inclusions from single crystals may be due to two phase entrapment, as inclusions homogenizing to the vapor phase are not uncommon, though most data cluster around normal histogram peaks (Browne *et al.*, 1976). There is a paucity of suitable fluid inclusion material from the relatively cool (<220°C) margins of the system. This is not surprising, given the fine grained nature of quartz forming at lower temperatures, with inclusions often giving spurious results (T. J. Reynolds, personal communication, 1989).

Samples from 300 to 1400 m depth have been analyzed (Table 2), though most are from 500 to 900 m depth. Subtracting the mean fluid inclusion temperature from the present measured temperature (= ΔT) at a given depth will indicate whether the local system has been heating or

Table 2. Fluid inclusion data for hydrothermal crystals from Broadlands wells (quartz crystals, unless otherwise noted)

Well	Depth (m)	Range, average (number of inclusions) Th°C	Range, average (number of inclusions) Tm°C	Measured[6] T°C	ΔT°C[7]
2	ejecta[2]	S[5]229–263, 255(27)	—	~249	−6
3	ejecta[2]	P222–295, 265(77)	−0.4 to −1.0, −0.68(5)	~246	−19
7	845[1]	P262–292, 288(18)	−0.3 to −0.4, −0.38 (4)	260	−28
		S244–268, 257(6)	−0.2 to −0.3, −0.21(16)	260	+3
7	893[1,2]	P288–296, 292(19)	—	272	−20
		S256–280, 270(46)	—	272	+2
7	896[3]	P249(2)	−0.9 to −1.1, −1.0(2)	277	+23
8	552[1]	P230–255, 247(14)	−0.8(6)	254	+7
16	347[1,9]	P192–222, 202(24)	−0.4 to −0.6, −0.56(5)	171	−31
11	520[4]	P262–272, 266(12)	−0.2 to −0.3, −0.28(6)	253	−13
18	602[4]	P266–276, 266(14)	−0.2 to −0.5, −0.25(5)	259	−11
19	790[1]	P252–276, 266(3)	−0.5(2)	276	+10
23	631[1]	P − S200–212, 210(5)	—	228	+18
24	579[1]	S230–232, 232(3)	—	262	+30
24	758[1]	P258–285, 268(58)	−0.3 to −0.5, −0.43(7)	274	+6
24	811[1]	P286–292, 288(7)	—	277	−11
		S250–280, 266(17)	—	277	+11
24	823[1,2]	P230–242, 240(10)	−0.8(2)	278	+38
24	841[1]	P246–280, 266(4)	−0.8(1)[8]	279	+13
		S232–282, 252(26)	—	279	+25
25	600[1]	P262–274, 270(7)	—	265	−5
		S230–272, 252(69)	−0.1 to −0.5, −0.38(16)	265	+13
25	680[2]	P246–280, 270(13)	−0.9(1)	272	+2
		S235–279, 255(31)	−0.4 to −0.6, −0.50(4)	272	+17
25	713[1,2,3]	P268–274, 270(87)	−0.3 to −0.4, −0.38(5)	274	+4
		S242–264, 255(50)	−0.7(10)	274	+19
27	ejecta[2]	P252–311, 285(72)	−0.7 to −1.7, −1.0(5)	~260	−25
29	436[2]	P194–283, 235(42)	−0.6 to −1.1, −0.85(2)	240	+5
		S201–264, 225(18)	—	240	+15
34	965[4]	S231–234, 232(9)	−0.9 to −2.0, −1.57(5)	210	−22
36	ejecta[2]	P256–284, 272(15)	—	~275	+3
		S246–281, 265(10)	—	275	+10
42	ejecta[4]	P267–307, 295(21)	−0.4 to −0.9, −0.5(5)	~256	−39
42	1210[4,9]	P253–300, 280(28)	—	268	−12
43	ejecta[4,9]	P290–314, 304(28)	−0.9 to −1.4, −1.15(4)	~278	−26
44	610[4,9]	P284–285, 285(8)	—	266	−19
44	1410[4,9]	P285(7)	—	285	0
45	490[4]	P249–263, 255(16)	−0.5 to −0.9, −0.6(7)	256	+1

[1] Browne *et al.*, 1976.

[2] Browne and Christie, personal communication, 1982.

[3] Hedenquist and Henley, 1985.

[4] Hedenquist, unpublished.

[5] P and S refer to primary and secondary inclusions; most data sets are for individual crystals.

[6] Where samples are ejecta, measured temperatures have been taken for the principal feed zone depth, determined from circulation losses and flow tests.

[7] ΔT = measured T − average Th. The average Th generally matches well with the observed histogram peak (Browne *et al.*, 1976). In some samples there are large ranges of Th, caused by a few discrepant inclusions. Although care was taken to avoid necked inclusions, this and/or two phase entrapment may be the cause.

[8] A value of +0.5°C was excluded, as it was probably due to CO_2 clathrate melting (Hedenquist and Henley, 1985).

[9] Calcite crystal, except 16-347, which is sphalerite.

cooling since inclusion formation. The curvature of the boiling temperature profile from 500 to 900 m is slight (only ±3°C deviation from a straight line); therefore, it is not unreasonable to compare heating or cooling (ΔT) results over the 500–900 m depth range. For example, 10°C apparent cooling from the time of fluid inclusion growth to the present could be caused by a drop in the hydrostatic head by about 90 m, or even by an increase in the gas partial pressure (which will depress the boiling profile). However, in the case of Broadlands, independent evidence suggests such cooling to be caused by the incursion of marginal waters (see below).

The pattern of thermal evolution at Broadlands, as indicated by comparing the mean of fluid inclusion homogenization temperatures with the present (i.e. predrilling) measured temperatures, is shown in Fig. 7. The fluid inclusion results for some wells (e.g. BR24) are complex, indicating either heating or cooling at different depths. For this general discussion, the ΔT values for each depth have been averaged for each well (except for the two inclusions from BR7-896, which were not included in the well average). However, when viewing the average well results, the variability in each well (due to variable degrees of dilution at different depths, etc.) must be kept in mind.

Major cooling is indicated in the eastern portion of the East Bank, with as much as 30°C cooling at 300–350 m depth in BR16; the present measured temperature at 650 m depth (150°C) is about 100°C below the boiling temperature for this depth. This cooling has not affected the alteration minerals nor their isotopic composition, as they record a normal, boiling temperature gradient (i.e. no inversion) across this zone (Eslinger and Savin, 1973). To a lesser extent (as far as the fluid inclusion data extend), the north and southwest margins of the West Bank have also suffered some cooling since peak fluid inclusion temperatures.

In contrast to this recent cooling deduced for marginal East and West Bank wells, there is good correlation between the fluid inclusion and present temperatures in the core of the East to West Bank production zone; in fact there appears to have been heating in some West Bank wells since fluid inclusion formation. Overall, the thermal change from east to west has a regular and consistent pattern for the wells with fluid inclusion data (Fig. 7).

In most cases, the range and average Th values for secondary inclusions are lower than of the primary inclusions (Table 2), and agree more closely with present measured temperatures, indicating that the secondary inclusions recorded the cooling event. This is similar to the Kirishima geothermal system (Taguchi and Hayashi, 1983), whose focus of activity has also shifted (associated with a drop in the upper surface of the geothermal water in a high relief terrane), resulting in as much as 100°C of cooling locally.

The progressive cooling at Broadlands around the margins, and particularly in the east, cannot be explained by a lowering hydrostatic head of the geothermal water. The association of a large thermal inversion with the major zone of cooling in BR16 suggests that incursion of marginal waters is the cause of the cooling in the east. This is supported by the composition of the fluids in the inclusions and discharged from the wells (see below).

FLUID CHEMISTRY

Initial discharge composition and downhole sampling

Broadlands well BR1 was drilled in 1965 and first discharged in 1966. Wells BR2 to BR25 were drilled from 1966 to 1971, with each in turn being discharged and sampled once the formation outside the well had heated to predrilling temperatures.

Most wells were discharged over long periods to test their output and the system's response to exploitation. From 1968 to 1971, 33.6 million tonnes of fluid were discharged (Hitchcock and Bixley, 1976). Thus the initial discharges of wells drilled near the end of this period may have not been entirely representative of the pre-1966 natural state.

Wells BR26 to BR36 were drilled and discharged between 1974 and 1979, while wells BR37 to BR45 were completed and sampled over the period of 1980–1984 (BR41 has not been drilled). A further 23.9 million tonnes of fluid were discharged prior to 1988, bringing the total to 57.5 million tonnes (equivalent to about two and a half years of the planned production); only 8% of this has been reinjected.

Much of the discharge and production test data are confidential. However, most of the initial discharge chemistry is available (Mahon and Finlayson, 1972; Ministry of Works and Development, 1977; DSIR files), and is listed in Table 3. These data are reported as analyzed, and are mainly for waters collected from the weirbox, separated at atmospheric pressure, but a few are waters collected from a Webre separator at pressures above atmospheric. In conjunction with measured enthalpies of discharge and the quartz geothermometer temperature of the fluid (the latter providing a good estimate of the feed zone temperature at Broadlands), steam fractions can be calculated and the fluid composition corrected to reservoir concentrations. Only total discharge gas concentrations are listed in Table 4 (see below), as correction for excess enthalpy conditions is based on tenuous assumptions.

Several wells on the margin of the system were not hot enough to discharge after reheating (e.g. BR6, 12, 16, 32, 34, 38, 39 and 40; Fig. 6), and required either to be airlifted, or sampled downhole. Table 5 lists recent downhole samples for several wells, some at two depths. These samples have been collected by a Klyen downhole sampler; some were collected by a sampler modified to seal in the initially dissolved gases, subsequently bled into caustic soda at atmospheric pressure after the sampler was recovered. Collection of this CO_2, which would otherwise escape when opening the sample bottle to atmospheric pressure, allows estimation of the dissolved CO_2 concentration of the marginal waters (see below).

Fluid types and evidence for boiling and mixing

The quartz and alkali (Na–K–Ca) geothermometer temperatures (as summarized by Fournier, 1981) have been calculated for the initial discharge samples, taking into account steam fraction (Table 6). For the weirbox waters, the chloride concentration in the reservoir has been corrected for the steam fraction (Table 6); the reservoir steam fraction due to "excess enthalpy" conditions has also been taken into account where necessary. A discharge is termed "excess enthalpy" when the feed zone is two phase, or where there is a separate vapor contribution to the well. In this situation, the measured enthalpy is higher than that expected for a liquid at the measured or geothermometer temperature of the feed zone, and the gas content of the total discharge is greater than that in the liquid reservoir. For the generally cooler downhole samples, measured temperatures are listed along with the chalcedony (Fournier, 1981) and alkali temperatures. A correction to the reservoir chloride concentrations is not necessary for downhole samples, as there is no steam fraction lost.

The reservoir liquid chloride concentration is plotted against the enthalpy of the reservoir liquid for each well in Fig. 8 to deduce the relationship between fluids across the system in its natural state, prior to significant discharge testing. Wells with an excess enthalpy discharge show simple steam gain trends from reservoir conditions (Hedenquist *et al.*, 1988), so that correcting for this effect allows mixing relationships to be identified.

Figure 8 shows a simple pattern of initial reservoir composition, with West Bank production wells having similar temperatures but fluids with slightly higher chloride concentrations than the East Bank production wells. Wells that are marginal to the East and West Bank production zones (Fig. 2) and are now used for injection or monitoring have water compositions which plot on a linear trend away from the production fluids and towards an endmember with zero chloride at a temperature of about 150°C. This marginal water, which dilutes the ascending chloride fluid, is steam-heated groundwater, hence the high temperature and zero chloride of the

Table 3. Initial discharge composition of Broadlands wells (all concentrations in mg/kg). Most analyses are collected from a weirbox (at atmospheric pressure); the rest are from a Webre separator. Data from Mahon and Finlayson (1972), Ministry of Works and Development (1977) and DSIR files. W.H.P. and C.P. refer to wellhead pressure and collection pressure

Well	Date	W.H.P. bar (gauge)	Enthalpy kJ/kg	C.P. bar (gauge)	Analysis T°C	pH	Li	Na	K	Ca	Mg	Rb	Cs	Cl	SO_4	B	SiO_2	HCO_3	NH_3
BR1	1/2/66	—	—	0.0	20	8.3	10.9	1065	152	4.6	—	0.6	0.6	1701	43	48.1	565	230	12
BR2	23/8/66	16.9	1256	0.0	20	8.30	11.7	1050	224	2.2	0.08	2.2	1.7	1743	8.0	48.4	805	178	2.1
BR3	28/4/67	17.6	1325	0.0	25	8.00	12.2	1035	213	3.0	0.80	1.80	1.80	1801	6.0	55.3	725	174	4.0
BR4	29/2/68	6.3	1849	0.0	25	8.02	12.0	1105	205	5.3	0.02	2.0	1.4	1986	2.0	61.0	500	145	2.5
BR5	14/11/67	8.2	—	0.0	20	9.1	4.9	1460	140	—	—	—	—	1142	—	23.4	—	1410	—
BR6	4/12/67	4.0	—	0.0	20	7.7	1.2	435	39	2.6	—	—	—	28	15	1.2	180	2284	—
BR7	15/5/68	12.0	2286	0.0	25	8.55	15.0	1300	234	1.3	0.01	2.40	1.80	1823	6.0	82.7	1000	944	1.0
BR8	29/2/68	11.2	1201	0.0	20	7.90	11.4	975	232	3.0	0.10	2.9	1.6	1858	3.5	52.6	796	157	2.3
BR9	27/11/68	10.1	1175	0.0	22	8.50	11.4	1005	212	4.8	0.36	2.40	1.50	1766	5.0	46.1	855	144	1.4
BR10	18/10/68	8.6	1100	0.0	22	8.60	9.5	910	142	1.1	0.05	1.10	1.40	1244	11.5	55.0	635	553	1.2
BR11	28/8/68	16.6	1222	0.0	20	8.25	12.2	1020	218	7.3	0.92	1.7	1.4	1794	10.0	48.9	805	78	1.3
BR12	5/12/68	4.1	930	0.0	20	8.95	10.0	1370	188	3.0	0.13	0.95	1.25	1461	35.0	41.0	450	239	—
BR13	27/11/68	15.0	1261	0.0	22	8.60	12.9	990	200	2.8	0.11	2.2	1.3	1664	2.5	48.6	780	168	1.5
BR14	6/2/69	16.2	1745	0.0	22	8.50	10.5	880	175	2.0	0.70	0.90	1.50	1482	6.0	47.4	844	218	1.4
BR15	3/4/70	19.6	1300	0.0	22	8.25	11.5	1060	207	5.7	0.13	1.80	1.55	1750	7.1	37.5	1126	310	2.0
BR16	16/1/70	—	—	0.0	20	8.25	6.25	570	85	8.5	7.46	0.51	0.47	528	4.5	40.6	265	555	12.0
BR17	24/4/70	13.1	1397	0.0	20	8.15	10.0	1000	224	4.8	0.00	1.86	1.88	1778	5.5	46.0	765	115	1.9
BR18	24/4/70	9.3	1815	0.0	20	7.80	11.2	1110	237	9.0	0.18	1.84	1.80	1985	4.0	58.5	635	250	3.0
BR19	24/4/70	11.2	1163	0.0	20	8.25	11.8	950	206	2.5	0.05	1.60	1.70	1720	20.6	48.2	875	175	1.9
BR20	2/8/71	11.0	1280	0.0	20	8.4	12.2	1020	209	2.8	0.03	1.8	2.0	1712	13.5	49.8	922	200	—
BR21	17/8/71	11.0	1901	0.0	20	8.2	12.3	1070	219	5.7	0.04	1.9	2.0	1893	17.5	59.7	951	134	5.7
BR22	4/8/71	11.6	1400	0.0	20	8.10	12.9	1054	228	2.6	0.03	2.0	2.0	1873	10.0	60.5	941	—	—
BR23	9/8/71	9.2	1043	0.0	20	8.40	12.2	1000	203	2.8	0.01	1.80	2.00	1656	12.0	51.7	853	220	—
BR24	18/11/71	7.1	—	0.0	21	—	11.1	1035	190	12.3	0.06	1.3	1.9	1704	11.2	47.6	784	—	—
BR25	15/7/71	31.2	1269	0.0	20	8.10	1.9	895	189	1.4	0.04	1.8	1.6	1429	14.5	51.6	1052	300	—
BR27	7/10/76	36.9	1310	9.6	20	6.42	8.8	750	115	1.6	0.07	1.05	1.7	1057	20.0	50.0	610	387	—
BR28	8/10/76	8.3	1316	0.0	20	8.12	11.4	910	155	1.3	0.07	1.55	1.65	1414	3.0	52.0	784	265	—
BR29	21/4/75	—	—	0.0	20	8.1	12.3	995	165	2.9	0.05	1.3	1.5	1280	20	70	810	—	—
BR31	28/5/81	8.2	1300	0.0	17	8.60	11.5	976	196	4.0	0.12	1.75	1.65	1616	9.0	45.7	778	142	—
BR33	5/1/84	3.5	880	2.6	26	8.60	9.6	869	96	2.6	0.05	0.88	1.18	1053	72.0	30.4	384	555	—
BR35	5/6/80	26.0	1146	4.0	19	7.66	—	790	136	1.0	0.02	—	—	1204	52.0	39.4	665	260	3.3
BR36	12/4/79	23.5	1725	0.0	22	8.14	12.6	985	177	1.2	—	1.66	1.55	1405	24.0	73.5	902	499	—
BR40	31/1/84	1.3	670	0.5	22	7.80	3.3	395	32	20.9	3.66	0.25	0.45	196	14.0	8.4	227	926	—
BR42	9/6/83	15.8	1635	0.0	15	8.74	10.6	941	158	2.0	0.05	1.22	1.34	1387	9.0	73.3	745	338	—
BR43	12/7/83	19.0	1320	0.0	12	8.43	11.0	902	184	1.4	0.09	1.76	1.50	1326	14.0	42.5	943	359	—
BR44	28/7/83	18.2	1740	0.0	19	8.04	9.0	769	117	5.9	0.01	1.11	1.09	1197	11.0	45.4	641	213	—
BR45	30/5/84	22.0	1370	0.0	21	8.63	11.0	840	148	3.4	0.11	1.45	1.37	1345	8.0	50.3	715	257	—

endmember. It also has a high dissolved CO_2 content (up to 0.5 mol; Hedenquist and Stewart, 1985 and Table 5) due to absorption of gas at depth from the condensed vapor, which ascends from the boiling chloride fluid beneath. The ~150°C CO_2-rich endmember water cannot result simply from dilution of deep chloride fluid with groundwater, as the endmember does not contain any chloride. Therefore, its only origin can be through steam-heating.

Although dilution of the deep fluid was noted earlier (Mahon and Finlayson, 1972), it was not until severe problems with shallow casing corrosion were first noticed (in December, 1983) that the characteristics and distribution of the steam-heated waters were more closely examined (Hedenquist and Stewart, 1985). Although they are high in bicarbonate, the H_2CO_3 dominates, hence they are properly termed CO_2 (or carbonic acid)-rich waters; the total carbonate in Table 5 is reported as bicarbonate, but can be speciated at any temperature given the pH at 25°C. These weak carbonic acid waters are very aggressive to standard geothermal grouts and stainless steel casings. Hence the recognition of CO_2-rich steam-heated waters early in the assessment of a system has a bearing on future development.

The physical processes occurring across the Broadlands system can be easily recognized from Fig. 8. Well BR15, at 2418 m the second deepest well at Broadlands (with production casing set at 1067 m), has the hottest and least diluted discharge, closest to the postulated parent fluid (Fig.

Table 4. Gas in total discharge fluid from Broadlands wells (mainly from early discharges), from gas analyses of Webre separator samples, multiplied by the steam fraction. Data are from Mahon and Finlayson (1972), Ministry of Works and Development (1977) and DSIR files

Well	Date	W.H.P. bar (gauge)	Enthalpy kJ/kg	G.P.	CO_2 mmol/100 mol total discharge	H_2S mmol/100 mol total discharge	CO_2/H_2S
BR1	28/2/66	3.1	2674	1.3	2770	7	396.0
BR2	30/9/66	30.7	1232	4.1	257.4	7.19	35.8
BR3	28/4/67	17.6	1325	15.1	1224.2	14.82	82.6
BR4	29/2/68	6.3	1848	3.0	1243.3	19.43	64.0
BR7	15/5/68	12.1	2286	11.8	2074.0	16.46	126.0
BR8	15/1/68	10.7	1200	5.8	676.7	13.32	50.8
BR9	27/11/68	10.1	1175	9.7	307.4	5.53	55.6
BR10	18/10/68	8.3	1107	8.3	543.9	4.06	134.0
BR11	29/8/68	15.2	1220	11.7	210.4	4.80	43.8
BR12	5/12/68	4.1	930	4.1	205.1	7.44	27.6
BR13	27/11/68	15.2	1261	14.5	262.8	6.00	43.8
BR14	6/2/69	16.2	1744	14.0	1775.9	21.07	84.3
BR15	15/12/69	15.6	1162	15.6	111.0	2.99	37.1
BR17	2/2/70	11.4	1508	10.9	455.6	9.88	46.1
BR18	31/3/70	12.2	1921	11.4	1810.9	20.95	86.4
BR19	2/4/70	11.2	1162	11.2	241.7	4.51	53.6
BR20	19/6/70	28.7	1169	28.7	251.0	3.51	71.5
BR21	28/10/70	11.9	2092	5.2	1379.0	22.2	62.1
BR22	28/10/70	15.1	1399	13.2	578.6	8.55	67.7
BR23	23/3/71	11.0	1042	2.7	168.8	3.33	50.7
BR24	27/6/84	18.0	1540	17.5	814.1	11.07	73.5
BR25	15/7/71	31.2	1269	30.5	513.0	5.61	91.4
BR27	7/10/76	37.9	1309	10.6	1292.8	11.11	116.4
BR28	8/10/76	9.3	1315	2.4	606.9	8.72	69.6
BR31	28/5/81	8.2	1300	3.4	276.0	6.47	42.7
BR33	5/1/84	3.5	880	2.6	111.5	1.65	67.6
BR35	5/80	26.5	1145	2.8	62.7	2.04	30.7
BR36	12/4/79	23.5	1725	3.3	1894.8	18.19	104.2
BR40	31/1/84	1.3	670	0.5	218.8	0.63	347.3
BR42	9/6/83	15.8	1635	3.8	1465.4	13.69	107.0
BR43	12/7/83	19.0	1320	8.5	1111.8	10.13	109.8
BR44	28/7/83	18.2	1740	4.0	1340.4	15.06	89.0
BR45	30/5/84	22.0	1370	7.0	465.8	6.19	75.3

Table 5. Composition of recently collected downhole samples (concentrations in mg/kg). Data from DSIR files

Well	Date	Depth (m)	Collection temp °C	Analysis temp °C	pH	Li	Na	K	Ca	Mg	Rb	Cs	Cl	SO_4	B	SiO_2	HCO_3	Corrected from CO_2 in caustic HCO_3	Corrected from CO_2 in caustic pH_{25}
BR1	20/6/84	550	223	20	6.14	3.71	829	79.0	14.7	2.0	0.49	1.02	1060	305	32.7	406	832	9861	4.7
BR2	9/10/87	450	248	22	8.7	9.9	885	131	7.1	0.35	1.18	1.16	1101	116	30.6	480	530	29570	4.62
BR3	2/12/87	600	246	20	6.4	9.1	723	155	6.5	0.21	0.21	1.17	1184	75	33.4	498	339	22820	4.23
BR4	2/12/87	318	226	21	6.09	9.1	649	124	11	0.19	1.02	1.03	851	67	22.8	385	583	9604	5.04
BR5	13/2/79	684	147	20	5.03	0.75	50	12	29.7	0.23	0.18	0.16	54	113	0.7	33	<5	—	—
BR6	31/8/87	670	63	18	7.0	0.93	398	31	15	20	0.08	0.08	30	96	1.4	190	1257	8492	5.44
BR6	24/3/86	850	129	22	7.08	1.3	500	40.9	7.3	56	—	—	25	19	<2.5	170	1144	17868	5.41
BR12	17/8/87	635	147	20	6.4	5.8	1359	210	17	0.62	0.99	1.03	1229	23	31.6	234	2463	19389	5.19
BR12	14/8/87	1300	270	20	6.4	7.4	869	138	9.9	0.68	0.82	1.02	1115	59	35.9	450	1117	—	—
BR16	8/8/84	650	150	22	6.49	4.8	652	56.0	2.4	5.9	0.32	0.5	333	101	24.2	215	965	9173	5.2
BR16	8/8/84	1200	270	22	8.13	8.6	529	—	3.2	0.83	0.45	0.8	824	201	64.8	454	146	—	—
BR32	15/12/87	608	91	27	6.3	0.1	153	24	14	2.5	0.05	0.06	50	66	<1	316	689	—	—
BR32	5/2/84	1050	200	24	7.7	5.5	2600	134	9.4	—	0.51	0.83	1074	—	36.6	182	4235	—	—
BR33	13/11/84	300	165	29	7.30	9.0	703	98.1	21.8	1.25	0.80	0.98	910	<5	28.5	372	586	2486	5.80
BR34	17/11/84	740	168	26	7.09	0.2	22	44.9	4.75	1.44	<0.55	<0.55	35	18	0.6	73	154	—	—
BR34	27/11/84	1250	233	25	6.58	4.2	786	68.1	12.8	0.55	0.35	0.89	933	75	24.8	214	410	—	—
BR38	6/3/86	680	150	25	6.44	—	170	8.8	9.7	0.9	—	—	59	11	<2.5	51	570	1235	5.89
BR39	10/2/82	800	42	23	7.43	0.54	350	17	54.4	48	0.12	0.10	28	—	1.2	140	750	—	—
BR39	10/2/82	1470	206	23	7.53	0.89	359	29	21.6	25	0.14	0.11	16	33	1.0	203	1154	—	—
BR40	25/3/86	350	131	20	6.01	4.8	534	43.3	20	1.8	—	—	326	18	13.6	250	2145	4283	5.62

The first HCO_3 value is for the downhole liquid after its CO_2 was bled into caustic at atmospheric pressure. The second column is corrected for the amount of CO_2 collected into the caustic; thus, the total CO_2 in these samples ranges from 0.02 to 0.48 mol. The corrected pH_{25} is that due to the total CO_2, if it were able to remain in solution at atmospheric pressure; this is the pH used in calculating the reservoir pH_{r} (Table 6).

Table 6: Derived Broadlands reservoir data

Well	Date	Enthalpy (H) kJ/kg	T_{Qtz} °C	H_{Qtz} kJ/kg	ex-H kJ/kg	T_{NKC} °C	T_{Res} °C	Cl_{Res} mg/kg	pH_T	log (Q/K)$_{kmf}$	log (Q/K)$_{cc}$	log a K/H	log a Na/H	log a Ca/H^2	log a Mg/H^2
BR1	20/6/84	D/H-223°[a]	223[b]	—	-	212	223	1060	5.71	−1.31	−0.63	2.86	4.11	7.02	5.65
BR2	23/8/66	1256	266	1164	92	293	266	1161	6.13–6.61	−0.49 to −0.01	−1.00 to −0.31	3.51–4.02	4.41–4.92	6.74–7.79	5.72–6.73
BR3	28/4/67	1325	257	1120	205	284	257	1234	5.56–8.00	−1.09 to +1.35	−1.97 to −0.40	2.88–3.84	3.79–4.76	5.68–7.58	5.62–7.52
BR4	29/2/68	1849	224	962	887	227	224	1407	7.20	+0.45	−0.35	4.62	5.58	9.39	—
BR4	2/12/87	D/H-226°[a]	217[b]	—	—	255	226	851	6.09	−0.71	−0.17	3.44	4.40	7.50	5.88
BR6	31/8/87	D/H-63°[a]	155[b]	—	—	185	63	30	5.33	−2.54	−1.50	2.16	3.50	6.85	7.27
BR6	24/3/86	D/H-156°[a]	147[b]	—	—	184	156	25	5.77	−1.77	−0.40	2.63	3.97	7.32	8.32
BR7	15/5/68	2286	269	1179	1107[c]	297	269	1009	7.72	+1.04	−0.58	5.06	6.03	8.83	7.72
BR7	23/9/80	975	240	1037	−62	263	240	1014	6.27	−0.53	−0.64	3.58	4.64	6.97	5.91
BR8	29/2/68	1201	265	1159	42	296	273	1217	5.58	−1.01	−1.17	2.99	3.84	5.86	4.89
BR9	27/11/68	1175	273	1200	−25	281	273	1177	6.01	−0.61	−0.48	3.39	4.29	6.88	6.26
BR10	18/10/68	1100	247	1071	29	275	254	870	6.08	−0.73	−1.10	3.33	4.36	6.15	5.46
BR11	28/8/68	1222	266	1164	58	276	277	1158	5.95	−0.66	−0.43	3.33	4.22	7.07	6.44
BR12	5/12/68	930	223	958	−28	263	223	1133	5.96	−0.79	−1.08	3.38	4.48	6.74	—
BR13	27/11/68	1261	263	1149	112	283	263	1122	6.25–6.85	−0.41 to +0.19	−0.95 to +0.03	3.57–4.22	4.49–5.15	7.00–8.35	6.21–7.48
BR14	6/2/69	1745	267	1169	576[c]	290	267	950	6.93	+0.20	+0.05	4.23	5.16	8.14	8.29
BR15	3/4/70	1300	304	1366	−66	273	304	1069	6.90	+0.30	+0.81	4.19	5.12	8.40	7.20
BR16	8/8/84	D/H-150°[a]	165[b]	—	—	219	150	333	5.57	−1.78	−1.74	2.63	3.93	6.19	6.93
BR17	24/4/70	1397	261	1139	258	283	261	1193	6.17–6.91	−0.42 to +0.32	−1.54 to +0.25	3.44–4.35	4.28–5.23	6.98–8.83	4.56–6.34
BR18	24/4/70	1815	242	1047	768[c]	269	242	1344	7.25	+0.64	+0.86	4.75	5.65	9.48	8.50
BR19	24/4/70	1163	278	1224	−61	291	278	1152	6.16	−0.64	−0.56	3.53	4.42	6.88	5.34
BR20	2/8/71	1280	279	1229	51	285	279	1094	—	—	—	—	—	—	—
BR21	17/8/71	1901	276	1216	685	269	276	1153	—	—	—	—	—	—	—
BR22	28/9/76	1231	277	1219	12	291	277	1135	6.16	−0.46	−0.77	3.53	4.47	6.70	—
BR23	9/8/71	1043	285	1262	−219	286	285	1201	6.53	−0.05	−0.01	3.91	4.82	7.54	5.48
BR25	15/7/71	1269	295	1316	−47	294	295	892	6.18	−0.45	−0.57	3.47	4.37	6.43	—
BR27	7/10/76	1310	258	1124	186	264	258	873	5.65–6.44	−1.17 to −0.38	−1.93 to −0.54	2.81–3.67	3.84–4.72	5.61–7.35	4.42–6.19
BR28	8/10/76	1316	263	1149	167	277	263	950	6.03–6.72	−0.74 to −0.05	−1.60 to −0.39	3.22–3.99	4.21–4.98	6.14–7.70	5.52–7.02
BR31	28/5/81	1300	263	1149	151	277	263	1089	6.22–6.88	−0.45 to +0.21	−0.94 to +0.18	3.51–4.24	4.43–5.17	7.10–8.59	5.95–7.41
BR32	15/12/87	D/H-91°[a]	198[b]	—	—	208	91	50	6.32	−1.55	−0.64	3.05	4.09	8.86	8.35
BR33	5/1/84	880	219	939	−59	240	219	912	6.47	0.52	0.53	3.66	4.85	7.57	6.11
BR35	5/6/80	1146	260	1134	12	281	260	925	6.66	−0.11	−0.57	3.93	4.93	7.58	5.73
BR36	12/4/79	1725	273	1200	525[c]	292	273	880	7.03	+0.32	0.00	4.32	5.29	7.93	—
BR38	6/3/86	D/H-150°[a]	73[b]	—	—	151	150	59	6.30	1.78	0.36	2.63	4.20	8.08	7.89
BR40	31/1/84	670	183	777	107	183	183	177	6.02	−1.50	−0.18	2.80	4.12	7.75	7.68
BR42	9/6/83	1635	257	1120	515	268	257	919	6.27–7.06	−0.51 to +0.28	−2.11 to +0.11	3.26–4.34	4.21–5.34	6.29–8.38	5.33–7.39
BR43	12/7/83	1320	281	1241	79	291	281	836	5.93–6.39	−0.74 to −0.38	−1.22 to −0.49	3.20–3.70	4.11–4.62	5.84–6.85	5.12–6.11
BR44	28/7/83	1740	244	1056	684[c]	251	244	811	6.99	−0.07	+0.37	4.17	5.22	8.99	6.62
BR45	30/5/84	1370	255	1110	260	265	255	914	6.30–7.06	−0.50 to +0.26	−1.27 to +0.30	3.15–4.32	4.42–5.31	6.98–8.80	6.00–7.77

The enthalpy (H) is as measured, except where noted. T_{Qtz} is the quartz geothermometer temperature (e.g. Fournier, 1981), except where noted. H_{Qtz} is the enthalpy for liquid at T_{Qtz}, while ex-H is the amount of excess enthalpy, i.e. measured enthalpy minus H_{Qtz}, at the feed to the well. T_{NKC} is the Na–K–Ca geothermometer temperature. T_{Res} is the temperature used for all reservoir chemistry calculations, based on quartz geothermometry, measured enthalpies and measured temperatures. Cl_{Res} is the reservoir chloride concentration, corrected for steam loss and excess enthalpy where necessary. The pH_T has been calculated at the reservoir temperature. The pH of the reservoir liquid is given as a range in the case of excess enthalpy conditions; the lower pH is calculated for all gas in the liquid, while the higher pH is calculated assuming equilibrium fractionation of gases between the liquid and the steam fraction in the reservoir (see Henley *et al.*, 1984). The actual pH of the reservoir will be intermediate to these extremes. The saturation index (log Q/K) is calculated for reaction (2), K-mica-K-feldspar (kmf), and for reaction (3), calcite (cc). A range of saturation indices are given when there are excess enthalpy conditions, as for pH. Activity ratios for K^+, Na^+, Ca^{++} and Mg^{++} over H^+ at reservoir conditions are also listed.

a – Where the sample is collected downhole, the measured temperature (°C) is listed in place of measured discharge enthalpy.

b – Where appropriate (Fournier, 1981), the chalcedony temperature is calculated instead of the quartz temperature (i.e. for the lower temperature downhole samples).

c – Where the excess enthalpy is particularly large, the subsequent calculations are only for an equilibrium two phase mixture in the reservoir (i.e. giving a high pH and log Q/K).

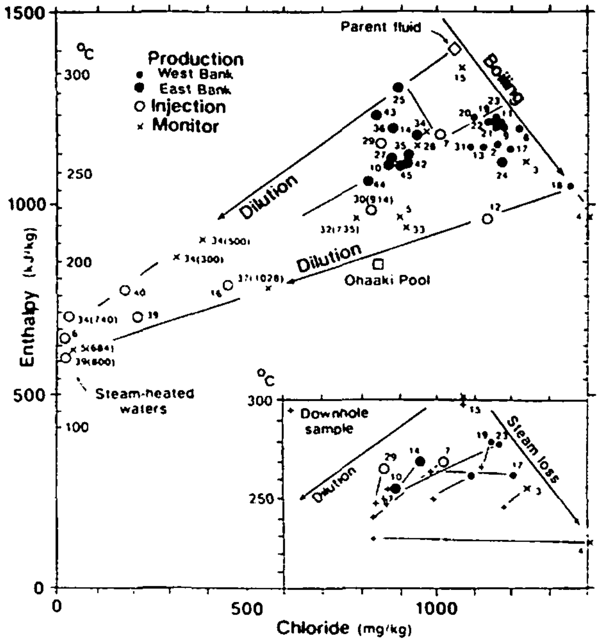

Fig. 8. Chloride-enthalpy plot of initial discharge compositions corrected for steam loss and excess enthalpy to quartz geothermometer or measured enthalpy temperatures (the latter if there is no excess enthalpy; Table 6). Early downhole samples are plotted at measured temperatures, with their depth shown in parentheses (m). East and West Bank wells are largely distinct from each other in terms of chloride, with the former showing evidence for deep dilution; the diluent is identified from marginal wells as being steam-heated, with a temperature of ~150°C (e.g. BR6). Downhole samples (+ symbols; Table 5) collected after extensive discharge (inset) indicate variable amounts of induced dilution by this steam-heated water. Modified from Hedenquist and Stewart (1985) and Hedenquist *et al.* (1988).

8). This parent fluid composition is determined from the intersection of the boiling trend for the least diluted reservoir liquid (BR18) and the dilution trend that lies over all reservoir liquid compositions. Most other wells have solid production casing set at only about 500 m depth, and produce from one or two principal zones located at about 500–1000 m depth. As can be seen from Fig. 8, East Bank production wells have reservoir fluids that must have been diluted from a parent fluid of composition similar to BR15 by mixing with 15–25% of steam-heated water at depths below the feed zones. In contrast, most West Bank production wells have reservoir fluids that are approximately the boiled equivalents of the parent fluid, with some showing very slight dilution.

As the deep chloride fluids ascend and eventually mix with the overlying and marginal carapace of steam-heated waters (Figs 3 and 4), they produce greatly diluted and cooled fluids; evidence for this extensive mixing comes from the composition of waters on the margin of the system in injection and monitor wells. These zones of mixing correspond to the measured temperature inversions noted in marginal wells (e.g. BR16 and 38) and at shallow levels over the production zone (e.g. BR3, 18, 19 and 33). Thermal inversions on the southwestern margin of the system at shallow levels (e.g. BR6, 39 and 40) are also evidence for lateral outflow along the major south southwest–north northeast structural trend (i.e. in the plane of the section of Fig. 4) from the West Bank upflow.

Ohaaki Pool is responsible for most of the natural chloride discharge to the surface. Its composition (Fig. 8) indicates that West Bank fluids are also diluted by steam-heated waters as they ascend to shallow depths. This is evidence for the proximity of the steam-heated waters to the northern margin of the system, where they probably extend over the upflow zone at shallow levels (i.e. BR3, 18, 33; Fig. 4).

Further evidence for the extensive distribution of the steam-heated waters comes from a comparison of reservoir compositions of initial discharges with recent (post-long term discharge test) downhole sampling (Fig. 8, inset). In most cases, production wells show a change in composition consistent with dilution by steam-heated waters, with the dilution having been induced by depressurization related to the discharge testing (Hedenquist *et al.*, 1988). This implies a relatively permeable connection between the marginal or shallow zones of steam-heated waters and the production zones.

This suggestion of a permeable connection is supported by Grant *et al.* (1983), who analyzed the pressure response to discharge testing. They estimated that during the pressure recovery following shutdown of the 1968 to 1971 discharge testing, approximately half of the fluid discharged was replaced by flow from the East Bank to the West Bank reservoir (of the 16 wells discharged during this period, all but two are located on the West Bank, hence drawdown in the West was greater). However, Grant *et al.* (1983) also estimated that a further third of the mass discharged was replaced "by downflow from the rhyolites above the reservoir", and "most of the 10 million tonnes lost from the (Ohaaki) rhyolite was in turn made up by return of water disposed at surface". Thus the carapace of steam-heated waters over and marginal to the East and West Bank upflows is in a delicate hydrologic balance, but will penetrate deeper into the system once the hydrodynamic head begins to decrease, naturally or due to exploitation.

Isotopic characteristics of Broadlands fluids

Further evidence for the origin of the marginal CO_2-rich, steam-heated waters comes from an isotope study (Fig. 9), conducted by Hedenquist and Stewart (1985). The isotopic composition of the fluids from the production wells (corrected for steam loss during sampling) are from Stewart (1978), and were collected in 1976. The downhole samples, as well as those of water level wells and local meteoric waters, were collected in 1984.

The local meteoric waters lie near to the meteoric water line, while samples from shallow (15 m) water level wells adjacent to the geothermal wells have a large scatter (Fig. 9a). Many of the shallow wells are hot and some are boiling; their waters have chloride contents varying from zero to 850 mg/kg (Fig. 9b). The isotopic enrichment of the zero chloride samples is probably due to evaporation related to steam-heating (Giggenbach and Stewart, 1982). It is not surprising that the zero chloride, steam-heated waters have isotopic compositions similar to groundwater, since the steam separated from the deep chloride fluid will have a composition only about +0.5‰ heavier in $\delta^{18}O$ from the meteoric trend (Fig. 9a) with its δD value dependent on the separation temperature; also, the steam component needed to heat cold groundwater to 150°C is only ~20%.

Downhole samples from the marginal wells generally plot between the deep chloride fluid composition and that of local meteoric water, both in terms of $\delta^{18}O$-δD and $\delta^{18}O$-Cl (Figs 9a and b), supporting the mixing relationship identified from the chloride–enthalpy plot (Fig. 8). The production well chloride fluids are shifted about +2.5‰ in $\delta^{18}O$ and about +5‰ in δD from the local meteoric water compositions; although the oxygen isotope shift may be largely due to water–rock interaction, the distinct hydrogen isotope shift may be evidence for the presence of a small component of magmatic water (Hedenquist, 1986). Broadlands residual gas chemistry (the non reactive N_2–Ar–He group and the higher hydrocarbons), as well as the high total gas content of the fluids (dominantly CO_2), indicate a dominant magmatic component for the gases (Giggenbach, 1986).

Despite evidence for a partial magmatic component to the fluids, it is not necessary to couple the origin of the gases to that of the water (Giggenbach, 1989a, b). This decoupling of the water

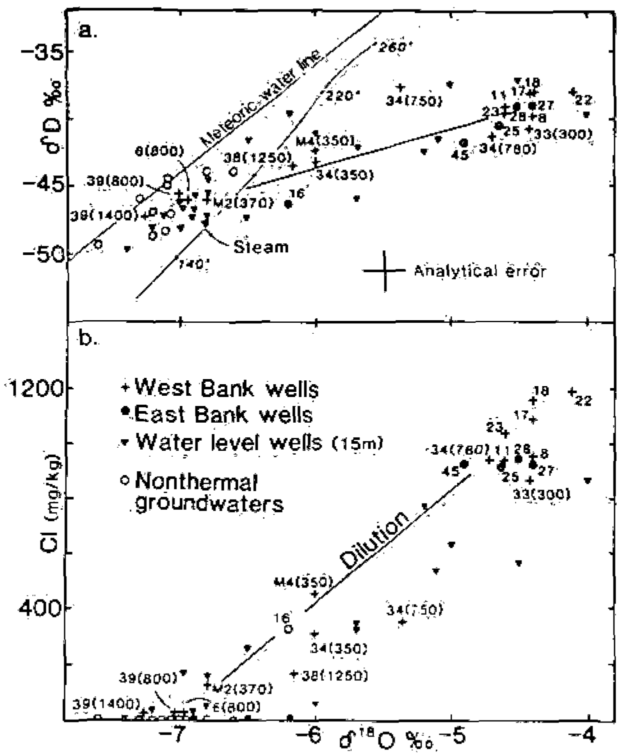

Fig. 9. (a) $\delta^{18}O$-δD plot of 1976 discharges of production wells (Stewart, 1978) and subsequent analyses of marginal wells, shallow water level wells, and local meteoric water. In conjunction with (b) $\delta^{18}O$-Cl compositions, these relations indicate the dilution of a deep chloride fluid by a steam-heated water. The composition of steam fractionated from a deep liquid (similar in composition to BR22) is shown for separation at 260 to 140°C; condensation of this steam into meteoric water will not greatly affect the isotopic composition of the latter. Modified from Hedenquist and Stewart (1985).

from gases (and possibly chloride) could be due to the transfer of heat and magmatic components in a layered, double diffusive convection cell (Griffiths, 1981). The $\delta^{13}C$ composition of Broadlands CO_2 and CH_4 (Giggenbach, 1982; Lyon and Hulston, 1984) also indicates a large magmatic component to the total carbon. This cell would separate the magma from the overlying meteoric convection, and could account for the observed variation in salinity and gas contents of geothermal systems in the Taupo Volcanic Zone (Giggenbach, 1989a, b).

Gas composition of the chloride fluids and steam-heated waters

Broadlands, along with Rotokawa and Kawerau, has one of the highest gas contents of New Zealand geothermal systems (Hedenquist and Henley, 1985, Fig. 1; Giggenbach, 1986, Fig. 2). This high gas content is related to its location along the eastern, andesitic arc margin of the Taupo Volcanic Zone (Giggenbach, 1986, 1989a, b; Henley, 1989), and the magmatic component to the gases.

The distinction between East Bank and West Bank chloride fluids (Fig. 8) is also evident in their N_2–Ar–He relationship (Giggenbach, 1986, 1989a, b). East Bank fluids appear to have a more "magmatic" signature (i.e. higher N_2/Ar and N_2/CO_2 ratios) than West Banks fluids. Assuming the same source for the deep fluids, this difference may be due to a greater degree (i.e. age) of water–rock interaction in the East than West. Thus the capacity of the host rocks in the East Bank to overprint or neutralize magmatic signatures of components in the fluids may now be less than in the West Bank (younger) portion of the system. In contrast, Giggenbach (1989b) proposes distinct sources of the gases for East and West Bank zones to explain the observed variations.

The gas concentrations in total discharge for the initial Broadlands samples are listed in Table 4. The CO_2 and H_2S concentrations reported account for $\geq 95\%$ of the total gases analyzed in the steam samples collected by Webre separator (Ellis and Mahon, 1977); these samples were generally collected at the same time as the weirbox liquid samples (residual gases such as N_2, H_2, CH_4, Ar, He, etc. are reported by Mahon and Finlayson, 1972; their relations are discussed by Giggenbach, 1980, 1986). The total discharge gas concentrations are determined from a calculation using the steam fraction at the sampling pressure.

In cases where the measured enthalpy and the enthalpy of the liquid at the quartz geothermometer temperature are similar (within analytical error for the two measurements, say ~60 kJ/kg), a single phase liquid feed to the well is indicated, and the gas in total discharge is equivalent to the dissolved gas concentration in the reservoir liquid. However, in situations where there is a two phase feed to the well (liquid plus vapor, i.e. excess enthalpy), determination of the original gas concentration in the liquid is not possible without assuming that all the excess steam came from the same zone as the liquid, and that equilibrium fractionation of the gases applies; the second assumption is demonstrated below to be doubtful.

All initial total discharge gas concentrations have been plotted on Fig. 10, and model curves calculated for gas fractionation between a boiling liquid and its corresponding vapor phase (Glover, 1970). The liquid model curve has been adjusted to be consistent with the lower limit of gas concentrations, passing just above most of the plotted data; higher gas concentrations are most likely due to two phase conditions of discharge, as noted by independent gas equilibria relationships (Giggenbach, 1980).

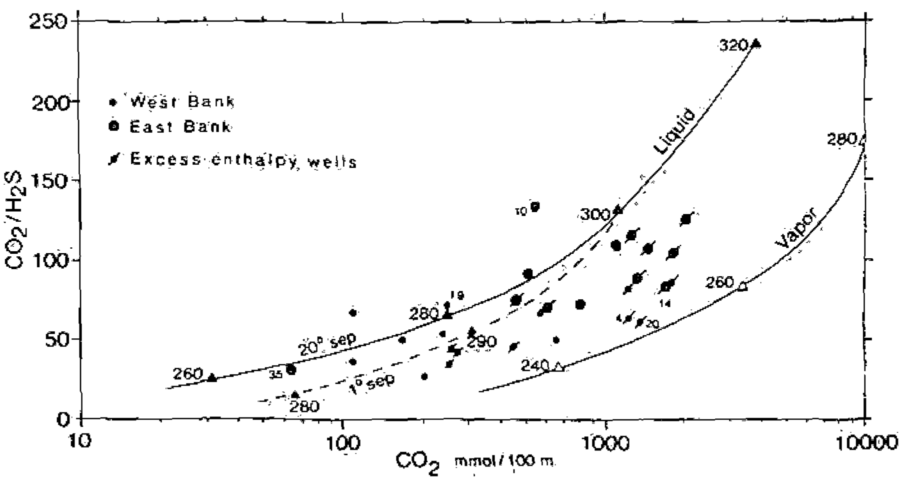

Fig. 10. CO_2 (mmol/100 mol) – CO_2/H_2S ratio for total discharge compositions (Table 4). The 20× variation in total CO_2 between wells, as well as the variation in CO_2/H_2S ratio, can be accounted for by gas loss from a boiling liquid, and/or a two-phase mixture of liquid plus vapor (i.e. excess enthalpy discharge). This situation has been modelled assuming a 280°C liquid of composition similar to BR19, with the parent 300°C liquid composition calculated for single step separation; the coexisting vapor composition has also been calculated for separation in 20°C steps. These endmember model curves envelop most of the gas data, with intermediate points resulting from excess enthalpy mixtures (e.g. BR4, 14 and 20 plotting near the vapor curve), or from continuous vapor separation from the 300°C parent fluid (modelled by 1°C steps—dashed line). The anomalously low H_2S for BR40 ($CO_2/H_2S = 347$; not plotted) is due to the dominance of the H_2S-depleted, steam-heated component; see text. The higher gas contents in total discharge for East Bank wells is due to the common occurrence of excess enthalpy conditions, which results from lower permeabilities here, possibly due to the abundance of illite deposited into fractures.

The initial (preboiling) gas content of the parent fluid at 300°C has been approximated by extrapolating the gas in liquid model curve, calculated to conform with the BR19 gas composition at 280°C (Fig. 10). This calculation gives a parent fluid that contains ~0.62 mol (2.7 wt%) CO_2, with a CO_2/H_2S ratio of 132 and a total H_2S of 0.0044 mol (0.015 wt%). A model curve (Fig. 6) of 0.6 mol CO_2 at 300°C (subsequently reduced through boiling during fluid ascent) closely matches the measured temperature profiles of wells in the upflow region. This total gas content is comparable with the 0.9 mol CO_2 estimated by modelling the vapor pressure–depth relationship (Sutton and McNabb, 1977) for the hot wells at Broadlands (i.e. their deviation from pure water vapor pressure curves).

The variations in gas concentrations between Broadlands wells are easily interpreted as due to boiling and gas loss, or to two phase (excess enthalpy) conditions existing in the reservoir. The excess enthalpy of discharge, probably due to relatively poor permeability, accounts for the anomalously high CO_2 in total discharges, particularly from East Bank wells. An exception to this simple pattern of gas chemistry is present in BR15, which has a very much lower CO_2 content and CO_2/H_2S ratio compared to that expected for such a hot and high chloride discharge (Fig. 8). This suggests that the BR15 Webre gas sample (not collected at the same time as the high temperature and high chloride weirbox water; Fig. 8) is not representative of the deep Broadlands liquid, but may be related to a shallower feed zone.

The gas concentrations of the steam-heated waters can be expected to vary depending on the degree of vapor condensation. Table 5 lists downhole samples of the steam-heated waters in which the gases (mainly CO_2) were trapped prior to depressurizing the sampler. These samples indicate total CO_2 concentrations varying between 0.02 and 0.50 mol, averaging about 0.15 mol. The CO_2 concentrations are reported as equivalent HCO_3^-, though at the given pH the majority of CO_2 is present as H_2CO_3.

Some of the low total CO_2 concentrations may be due to leakage of the sampler during ascent, while some very high concentrations (not reported in Table 5) are probably due to flashing into the sampler when it was triggered at depth (as evidenced by low sample volumes). However, the analyses reported here probably represent a reasonable range of CO_2 values to expect in these steam-heated waters (several duplicate samples showed the technique to be reproducible). Thus, the CO_2 content in the steam-heated waters is similar to somewhat less than the concentration in the deep chloride liquid.

The H_2S analyzed in the downhole samples of the steam-heated waters was often below detection. Where detected, however, the resulting CO_2/H_2S ratio varied from 300 to 1000; this is in agreement with a discharge and Webre sample of one of the steam-heated waters (BR40; Table 1). The elevated CO_2/H_2S ratio in the steam-heated waters is consistent with trends to higher CO_2/H_2S of production fluids that show mixing with steam-heated water (Hedenquist *et al.*, 1988).

This increase in CO_2/H_2S ratio is primarily caused by a relative depletion in H_2S, which may be due to one or more of at least three processes (Hedenquist *et al.*, 1988): (1) H_2S is more soluble in the boiling liquid so that CO_2 is enriched in the initial steam (Fig. 10), and therefore will also be relatively enriched in the condensate; (2) H_2S is partly oxidized upon condensing into the steam-heated groundwaters (elevated sulfate concentrations are noted, from 20 to 300 mg/kg, but not to the extent of producing acid conditions); (3) some of the H_2S is fixed as iron sulfide (pyrite is a common alteration mineral associated with the CO_2-rich, steam-heated waters at Broadlands, and can reach 8 wt% at shallow levels in BR16; Ewers and Keays, 1977).

Patterns in fluid composition from fluid inclusion data

The variation in temperature and fluid composition across the Broadlands system can also be detected from systematic changes of fluid inclusion data. As previously discussed, the fluid inclusions trapped by hydrothermal crystals (mainly quartz, but also some calcite) at Broadlands record a higher-temperature at the time of their formation than now prevails in a portion of the East Bank production zone and the margins of the West Bank.

In order to assess the boiling and mixing relations from fluid inclusion data, homogenization (Th) versus ice melting (Tm) data have been plotted (Fig. 11). This plot is similar in style to the chloride–enthalpy mixing diagram (Fig. 8), except that Tm is a measure of all dissolved components in the fluid, not just chloride (Hedenquist and Henley, 1985). Therefore, CO_2 in solution will also make a significant, and sometimes dominant, contribution to Tm. Most production wells have a fluid with total molality of dissolved salts (Na + K − Ca + Cl + . . .) of about 0.05 mol (0.2 wt% NaCl equivalent), whereas CO_2 is often 0.1 to 0.3 mol. This means that CO_2 will contribute from two to six times as much to the Tm as will the salts. Hence boiling and consequent gas loss will have a large effect on Tm (e.g. 50% of a liquid's CO_2 content is lost as it cools by open system boiling from 260 to 255°C).

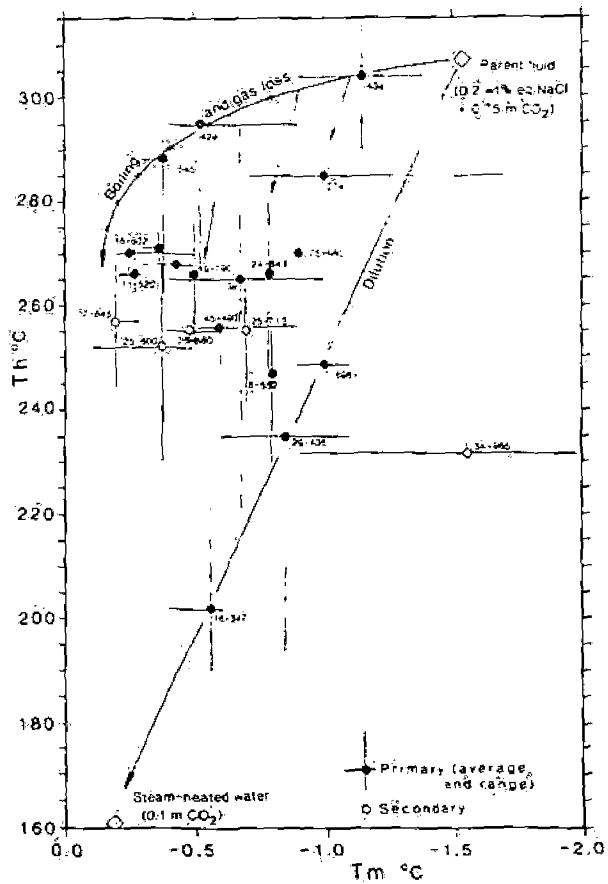

Fig. 11. Th–Tm plot of fluid inclusion data, with well and meter depth for some samples. Two trends are apparent, one is dilution (mixing) from high to lower temperature (through BR16-347); the other data fit a gas loss (boiling) curve (calculated for 5°C, multistep separation), or are enveloped by the curves for the two endmember processes. Compare with the chloride-enthalpy plot of present fluids (Fig. 8), where marginal wells BR7, 16, and 29 also show evidence for dilution. The deep paleo-fluid had a preboiled CO_2 content of ~0.75 mol at ~307°C (assuming 0.2 wt% NaCl equiv. was also present), based on intersection of these two trends. The diluent had a temperature of ~160°C from extrapolation of the dilution trend (assuming zero chloride and ~0.1 mol CO_2 content). The BR34-965 sample contains secondary inclusions in a quartz phenocryst. Modified from Hedenquist and Henley (1985).

Th and Tm data from Broadlands fluid inclusions can be interpreted in terms of a boiling (and gas loss) trend, and a dilution trend, just as in the chloride–enthalpy diagram (Fig. 8) for present day fluids. Samples plotting between the two endmember trends indicate that both processes have occurred (again, as noted for present day fluids). The paleo-dilution trend is defined by a straight line though data points including marginal wells BR7, 16 and 29. The boiling trend has been calculated assuming single stage steam and gas loss (Henley *et al.*, 1984; Hedenquist and Henley, 1985) such that it envelopes as close as possible the high temperature and partially degassed data of BR7, 42, and 43. Since boiling and mixing are the two dominant processes in geothermal systems (Giggenbach and Stewart, 1982), a combination of these two trends should account for most of the variation in the data.

Extrapolation of these two trends to high temperature define the temperature and composition of the paleo-parent fluid (unboiled and undiluted). This is approximately 307°C. Assuming that the present salinity of 0.2 wt% NaCl equivalent has remained approximately constant (i.e. contributing ~ −0.12°C to Tm), the gas content would be about 0.75 mol CO_2 (3.3 wt%) in order to account for −1.4°C of the −1.5°C Tm (Fig. 11). This agrees closely with the parent fluid temperature estimated by intersection of dilution and boiling trends for present day fluids (Fig. 8), and is similar to the present gas content of the parent fluid of 0.62 mol CO_2 (Fig. 10). Extrapolation of the fluid inclusion dilution trend to lower temperatures indicates an endmember steam-heated water of about 160°C, depending on its CO_2 content (i.e. its Tm value, in this case assumed to be 0.1 mol). Again, this estimate is consistent with the temperature and CO_2 content of present day steam-heated waters (Fig. 8 and Table 5).

CO_2 clathrates were not observed, except possibly in one case by Browne *et al.* (1976). This is consistent with the minimum CO_2 of ~0.9 mol necessary for clathrate formation (Hedenquist and Henley, 1985). The lowest Tm values only just approximate this minimum CO_2 value for clathrate formation, assuming −0.12°C being contributed by salts and the balance by CO_2. Clathrate formation was not observed in the small inclusions with low Tm in BR34.

The fluid inclusions and their host crystals do not have an established chronology. However, individual variation in fluid temperature and chemistry is recorded in the fluid inclusion data plotted on Fig. 11. For example, well BR7, which lies on the eastern margin of the system, and well BR24, which is located between the East and West Bank production zone, both show large variations over small vertical ranges. This may be caused by intermittent and/or local incursions of cool, diluting fluid. Variations in the degree of boiling (related to periods of depressurization caused by fracturing?) may also explain the large variations in Tm (i.e. large variations in dissolved gas contents), particularly where there is little variation in Th (e.g. BR34-965). Therefore, the magnitude and duration of boiling and dilution have been variable over the life of the Broadlands system, though in general the paleo-patterns are in agreement with those deduced for the present system.

Overall, the fluid inclusion data show that boiling of a CO_2-rich deep fluid has been occurring since fluid inclusions have been forming, and that a steam-heated water has been present and acting as a dilutent in a manner similar to that at present. The presence of dilute, steam-heated waters may be more extensive now than during growth of fluid inclusions in marginal wells, as indicated by the change in temperatures (Fig. 7).

SATURATION CONDITIONS FOR RESERVOIR FLUIDS

The weirbox water and Webre gas analyses allow the total discharge composition of each well fluid to be determined. Where there is a single liquid feed to the well, the total discharge composition is representative of the reservoir liquid and can be speciated to the feed zone temperature, providing activities and partial pressures of components. If there are excess enthalpy conditions, activities for most nonvolatile components can be closely estimated after correction for the steam fraction in the feed zone. However, the partial pressures of gases in the reservoir liquid component of the excess enthalpy discharges are less certain, and will lie within a range that will encompass the actual value (as discussed below). A calculation of reservoir liquid activity ratios incorporating H^+ is also difficult in this case, and their relevance is limited.

Data from Tables 3, 4 and 5 have been speciated to their reservoir conditions by means of a modified version of the program ENTHALP (Truesdell and Singers, 1974). In addition to the reservoir temperature (deduced from silica and Na–K–Ca geothermometry and measured enthalpies and temperatures) and an estimation of the degree of excess enthalpy (ex H), values for reservoir pH and the state of calcite and K-feldspar-K-mica saturation have been calculated (Table 6).

Excess enthalpy conditions

When a geothermal well discharges a fluid that is two phase (excess enthalpy) at the reservoir feed point(s), determination of the gas composition of the liquid phase is complicated. Calculation of the steam fraction at the feed to a well is possible through an iterative process using the silica concentration to estimate the feed temperature (R. B. Glover, personal communication, 1983). Calculation of the feed zone temperature thus allows a correction of total discharge concentrations of nonvolatile species to their concentrations in the reservoir liquid. However, correction of gas concentrations is more difficult, as it assumes equilibrium fractionation of gases between the liquid and vapor, which is not always observed in the case of Broadlands (see below).

The gas compositions plotted on Fig. 10 can best be explained by a variable mixture of liquid and steam, with the wells having the largest excess enthalpy (Tables 3, 4 and 6) plotting furthest from the liquid equilibrium gas loss curve. An estimate of the degree of steam fraction in the reservoir may also be independently estimated by assessing the deviation of discharge gas composition from that expected for equilibrium of the reaction (Giggenbach, 1980):

$$CO_2 + 4H_2 = 2H_2O + CH_4. \tag{1}$$

Analytical quotients of initial discharges for which residual gas data (H_2, CH_4, etc.) are available (Mahon and Finlayson, 1972; DSIR files) are plotted on Fig. 12. As noted by Giggenbach (1980), who plotted 1976 data for BR11, 23 and 25 (all production wells), Broadlands residual gas composition approximates equilibrium conditions for reaction (1). This gas equilibrium is also supported by the values for the initial discharges of BR9, 11 and 13 (all production wells with single phase liquid feeds; Table 6). However, several initial discharge compositions plot in the vapor addition field, as would be expected for their excess enthalpies of discharge (Table 6); in particular, BR4, 7, 14 and 24 have 600 to 1100 kJ/kg excess enthalpy, and plot furthest into the vapor addition field. Two exceptions are BR10 and 12, which plot in the vapor addition field but are not excess enthalpy (Table 6). These discrepancies and the effect of excess enthalpy conditions on the calculated mineral saturation states are discussed in the following section. The effects of recent drawdown and depressurization of the reservoir show up in gas data which plot along a gas loss (i.e. boiling) trend (Hedenquist *et al.*, 1988).

Mineral–fluid equilibria

Prior to the investigation of detailed mineral–fluid equilibria relations (Lonker *et al.*, in press), it is useful to make a general assessment of the state of saturation of Broadlands fluids with respect to the dominant mineral assemblage. In order to do this, the affinity (Giggenbach, 1984) has been calculated for the reactions:

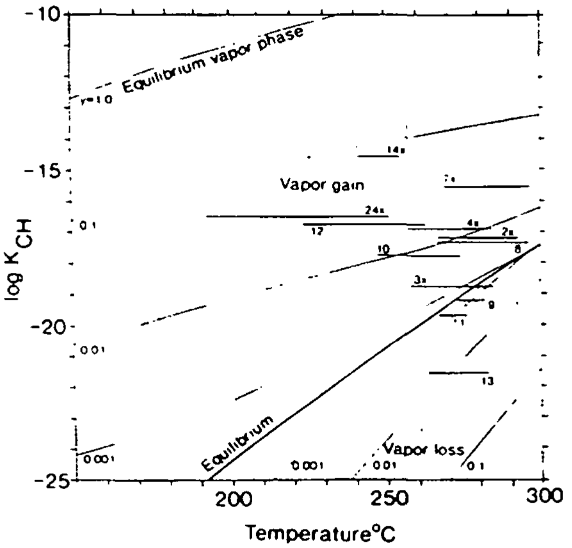

Fig. 12. Plot of temperature (of quartz and Na–K–Ca geothermometers) versus log K for reaction (1), illustrating the effect of steam loss (boiling) and steam gain (excess enthalpy discharges indicated by ×) on CO_2–H_2–CH_4 gas equilibria (Giggenbach, 1980).

$$3KAlSi_3O_8 + 2H^+ = KAl_3Si_3O_{10}(OH)_2 + 6SiO_2 + 2K^+ \quad (2)$$

and

$$CaCO_3 + CO_2 + H_2O = 2HCO_3^- + Ca^{++}. \quad (3)$$

These affinity values (saturation indices) are plotted on Figs 13a, b versus the reservoir temperature used for the calculations (Table 6). The wells tapping a liquid phase have saturations (log (Q/K), where Q is the analytical quotient for the reaction) for the K-feldspar-K-mica reaction of about −0.4 to −1.0, though the lower temperature (marginal) wells have indices of −1.4 to −2.5. Thus, almost all wells are undersaturated with respect to K-feldspar (adularia), and are stable relative to K-mica (illite). This is also the situation for calcite saturation (reaction 3), with saturation indices ranging from −0.5 to −1.1 (indicating undersaturation), though the lower temperature (<200°C) wells are more variable (−0.2 to −1.7).

The notable exceptions to these patterns are BR15 (the deepest and hottest feed of any well), and the excess enthalpy wells. The BR15 gas concentrations have already been suggested to be an artifact of sampling (Fig. 10), and will not be considered further. The excess enthalpy discharges (where measured $H > H_{Qtz}$ by >60 kJ/kg; i.e. the error for enthalpy measurements) have had two calculations performed. The first assumes all gas is in the liquid phase, and the second that there is equilibrium fractionation of gas between liquid and vapor (Giggenbach, 1980; Henley *et al.*, 1984); wells with >500 kJ/kg excess enthalpy are only calculated for the latter situation.

The first set of calculations (all gas in the discharge assumed to be in the reservoir liquid) gives log Q/K values generally lower than the wells without excess enthalpies (due to the artificially low calculated pH values). The second calculation results in values that are higher than those for the non excess enthalpy wells, mostly indicating K-feldspar and calcite supersaturation (Figs 13a, b). It appears that the true pH (and therefore saturation index) of the reservoir liquid associated with these excess enthalpy wells will be between the two calculated values (i.e. equilibrium fractionation of gases between liquid and vapor does not adequately model the

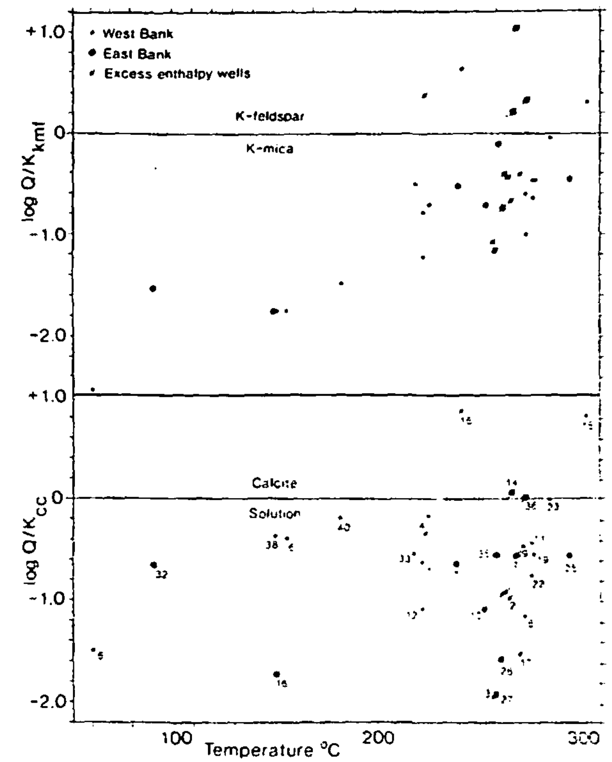

Fig. 13. (a) Plot of reservoir temperature versus saturation index (log Q/K) for equilibria between K-feldspar and K-mica, reaction (2). Ranges of log (Q/K) are for single and two phase calculations of excess enthalpy discharges. (b) Temperature versus calcite saturation index. All Broadlands fluids appear to be undersaturated with respect to K-feldspar (adularia) and calcite, except for those with excess enthalpies, which are due to an artifact of the calculation.

excess enthalpy situation). Therefore, all wells with excess enthalpy discharges are excluded from further discussion due to the uncertainties arising from the gas distribution between liquid and vapor in the local and discharge-induced two phase portions of the reservoir.

The undersaturation of Broadlands fluids with respect to adularia and calcite must be reconciled with the observation (Browne and Ellis, 1970) of these two minerals being common, particularly as fracture fillings. One possible explanation may be that boiling of a fluid in high permeability fractures leads to sufficient gas loss from the liquid to cause both minerals to precipitate in fractures, as observed. This contrasts with the rock-dominated fluids present in the formation. This distinction in mineral–fluid equilibria between wallrock and fractures is supported by the common presence of illite in the wallrock (Browne, 1973a).

The marginal CO_2-rich, steam-heated waters are also undersaturated with respect to adularia and calcite. However, effervescence of BR6 waters during discharge caused aragonite to precipitate (Browne, 1973b), supporting the suggestion that extensive boiling and gas loss in fractures can lead to carbonate saturation. Relatively recent mixing of deep fluids with the marginal CO_2-rich steam-heated waters may also account for the present undersaturation with respect to calcite and adularia (see below), though etch textures in these minerals have not been noted (Lonker *et al.*, in press).

Giggenbach (1980) noted that the deep production fluids at Broadlands have H_2/H_2S ratios in accord with equilibrium between pyrite and ferrous iron (FeO) present in a silicate mineral, probably chlorite, and suggested the reaction:

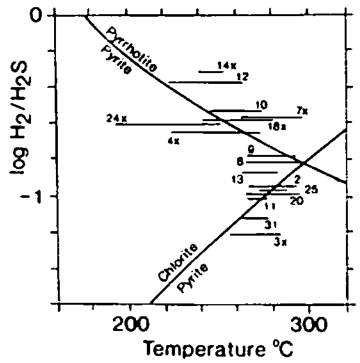

Fig. 14. Temperature versus log H_2/H_2S for pyrite-Fe silicate and pyrite–pyrrhotite equilibria (Giggenbach, 1980) for reactions (4) and (5). Most data reflect pyrite-Fe silicate (chlorite) control on H_2/H_2S (those for excess enthalpy wells, labelled with ×, have high H_2 due to fractionation effects). Exceptions are BR10 and 12, whose gas data suggest pyrite–pyrrhotite control on the margins of the system, consistent with the mineral assemblage here.

$$FeS_2 + H_2 + H_2O = FeO\,(\text{silicate}) + 2H_2S. \tag{4}$$

This reaction is supported by the initial discharge gas chemistry (Mahon and Finlayson, 1972; DSIR files) for production wells such as BR3, 8, 9, 11, 13, 20, 25 and 31 (Fig. 14), which have little or no excess enthalpies (Table 6). However, several other wells with higher H_2/H_2S ratios do not agree with pyrite–chlorite equilibria (e.g. BR4, 7, 10, 12, 18 and 24); for their reservoir temperatures, a much lower H_2/H_2S ratio would be expected. This can be explained for wells BR4, 7, 18 and 24 by the excess enthalpies of discharge (Table 6 and Mahon and Finlayson, 1972). Since H_2 fractionates much more strongly into the vapor phase than does H_2S (Ellis and Mahon, 1977; Giggenbach, 1980), vapor-rich excess enthalpy wells will have fluids with much higher H_2/H_2S ratios than the parent liquid (Fig. 12).

The anomalous H_2/H_2S ratio for BR10 and 12 (also anomalous for CO_2–H_2–CH_4 equilibria; Fig. 12), however, cannot be explained by vapor-rich discharges, as they are not excess enthalpy wells (Table 6). Rather, they agree with H_2/H_2S ratios expected for pyrite–pyrrhotite equilibria:

$$FeS_2 + H_2 = FeS + H_2S. \tag{5}$$

This is similar to Waiotapu (Hedenquist, 1983a), where the relatively reducing (high H_2) conditions are probably due to organic carbon present in lacustrine beds (Hedenquist and Browne, 1989). There pyrrhotite being pseudomorphed by pyrite is good evidence that reaction (5) controls the H_2/H_2S ratios.

Pyrrhotite at Broadlands is restricted to local occurrences in BR1, 4, 5, 7, 12, 13, 14, 15, 16, 27, 34 and 39 (Browne, 1971a, 1973a; Wood, 1983). Given its occurrence primarily on the margins of the system, its presence may indicate either its formation from reduced groundwater (interacting with organic carbon-containing lacustrine beds; Lonker *et al.*, in press; Hedenquist and Browne, 1989) and/or an association with the steam-heated water (Fig. 8). The latter would explain the anomalously high H_2/H_2S ratio for BR10 and 12 fluid (residual gas analyses are not available for other non-excess enthalpy marginal wells). However, the Fe-deficient and corroding pyrrhotite in BR12 (Lonker *et al.*, in press) may be evidence that pyrite–pyrrhotite reaction is controlling the H_2/H_2S ratio, as noted at Waiotapu, rather than the reverse.

Thus, the saturation indices and gas partial pressures from wells with reliable discharge compositions (i.e. wells without excess enthalpy conditions) indicate calcite undersaturation, and equilibria with K-mica, chlorite and pyrite. Marginal wells with a component of CO_2-rich, steam-heated waters have lower temperatures and higher acidities than the production wells, leading to greater undersaturation with respect to calcite and adularia, and pyrite–pyrrhotite equilibria (the latter reflecting a relative depletion in H_2S). These slightly acid, CO_2-rich waters may also be related to the deep (to 1000 m) occurrences of siderite and kaolinite (Table 1) on the margins of the system. The siderite forms due to the relatively high iron in the groundwater component of the steam-heated waters, while the kaolin becomes stable at the 150°C and gas-rich conditions at the margins of the system (see below).

Dilution and cooling of the chloride fluids by the steam-heated waters, particularly on the eastern margin of the system, may also explain the common occurrence there of sphalerite and galena through a reaction of the form:

$$(Pb, Zn)S + 2H^+ + mCl^- = (Pb, Zn)Cl_n^{2-n} + H_2S \qquad (6)$$

(Seward, 1984; Ruaya and Seward, 1986), though the actual complex responsible for metal transport may be a mixed ligand species. The unetched nature of the sphalerite and galena at depths below 500 m (Weissberg *et al.*, 1979) indicates that they could be in equilibrium with the present (diluted) fluids. Shallow (350 m deep) sphalerite is etched in BR16 (P. R. L. Browne, personal communication, 1989), suggesting that the extensive dilution at this level has now resulted in sphalerite instability.

THE GEOCHEMICAL EVOLUTION OF DEEP FLUIDS DURING ASCENT

The deep fluids at Broadlands, prior to the initiation of boiling at depths of ~1500 m, have temperatures in excess of 300°C (Figs 3, 4, and 6). They are best represented in terms of temperature and liquid composition (Fig. 8) by the deep discharge of BR15 (cased to 1067 m), though the deep gas concentrations have had to be estimated by extrapolating model curves to 300°C.

These deep fluids are close to "full equilibrium" (Giggenbach, 1984, 1988) with K- and Na-feldspars (Fig. 15). As they begin to boil during ascent, they cool and quickly shift from Na/K feldspar equilibrium; in effect, the high temperature equilibrium value of the a_{Na^+}/a_{K^+} ratio is "frozen in", particularly in the West Bank production well (upflow) fluids (Fig. 15). This boiling trend, with little cooling by dilution, is supported by the observed chloride–enthalpy relationships (Fig. 8). In contrast, the ascent of fluids in the East Bank involves relatively deep (>1000 m) mixing with steam-heated waters (Fig. 8) prior to their discharge to production wells.

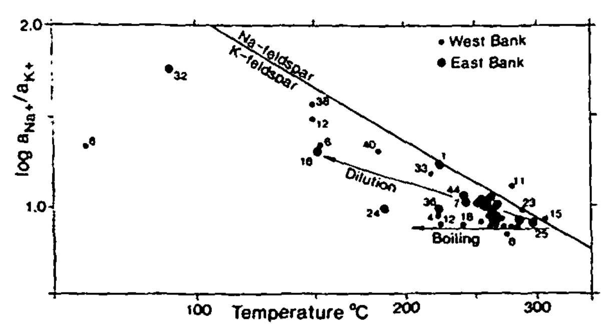

Fig. 15. Temperature–log (a_{Na^+}/a_{K^+}) relationship (Giggenbach, 1984) for Broadlands fluids, suggesting that the ascending West Bank fluids "freeze-in" a Na–K feldspar equilibria of ~300°C, while East Bank fluids equilibrate to lower temperatures and/or are diluted by marginal waters of lower Na/K ratio than expected for Na–K feldspar equilibria.

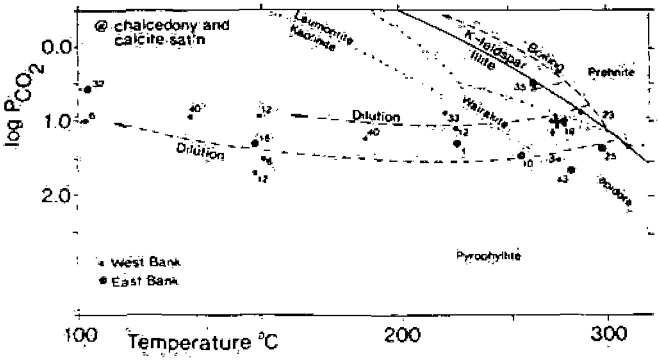

Fig. 16. Temperature–P_{CO_2} (bars) relationship (Giggenbach, 1984) for Broadlands fluids (excluding those with excess enthalpy conditions, i.e. a majority of East Bank producing wells). Although boiling will locally cause a fluid to become K-feldspar (adularia) stable, small amounts of dilution will return it to K-mica (illite) stability. Continued dilution by the steam-heated waters eventually precludes a fluid ever regaining adularia stability, both in chemical terms as well as physically; this is because mixing removes the ascending liquid from its vapor-saturation temperature, i.e. it can no longer boil. Continued cooling by dilution, whether it be with CO_2-rich, steam-heated waters or by cool groundwater, provides the opportunity for kaolinite stability to be reached over that of illite–smectite, due to the increasing dissociation of H_2CO_3 with decreasing temperature. This accounts for the occurrence of kaolinite at depth on the margins of the system (Table 1).

This dilution shifts the deep fluid from Na–K feldspar equilibrium, since the diluent has a relatively low Na^+/K^+ ratio compared to feldspar equilibrium (Fig. 15). It is likely that equilibria other than that involving the feldspars controls the lower temperature Na^+/K^+ ratios of the steam-heated waters; this may relate to the fixation of K^+ into clay minerals (Giggenbach, 1988), the latter being particularly common at Broadlands (Table 1).

The shift of Broadlands mineral–fluid equilibria from a "full equilibrium" assemblage (Giggenbach, 1984, 1988) of Na-feldspar-K-feldspar into the K-mica stability field is mainly due to the dilution of the deep fluid by marginal steam-heated waters (Fig. 8), as boiling by the ascending fluid generally favors K-feldspar stability. This shift in mineral stability is reflected in the trends depicted on Fig. 16, where small amounts of mixing with a cooler water quickly removes a fluid from the K-feldspar stable boiling path into the stability field of K-mica. Despite resumption of boiling after dilution, it is difficult for a fluid to evolve sufficient CO_2 at lower temperature to again become saturated with respect to K-feldspar. Extensive boiling and steam loss would be most common in fractures, where a fluid boils during ascent with little interaction with the rock (e.g. the fluid discharged from BR35 is just K-feldspar stable (Fig. 16), and has the lowest gas content of Broadlands wells; Table 4). Vein adularia has been used to indicate zones of high permeability (i.e. high fluid flow and boiling) at Broadlands and elsewhere (Browne and Ellis, 1970; Browne, 1978).

The shift to illite (and even kaolinite) stability at Broadlands is hastened by the fact that the diluent is steam-heated and CO_2-rich (Fig. 16). The abundance of illite (Browne, 1971a, 1973a; Hedenquist, 1983b) in core from East Bank wells is consistent with the shift in mineral stability (Fig. 16) expected from the degree of dilution of East Bank production fluids when compared with that of the West Bank fluids (Fig. 8). This increased dilution in the East Bank, and its favoring of illite deposition, may account for lower permeabilities (and resultant excess enthalpy conditions) present in comparison with West Bank wells.

The interstratified illite–smectite at shallow levels over the deep upflow, along with minor occurrences of kaolinite (e.g. BR31; Table 2) is consistent with the presence of relatively cool, steam-heated waters. These waters may cool even more on the deeper margins of the system, explaining the more common occurrence of kaolinite here (Table 1); the stability of kaolinite over illite at lower temperatures (Fig. 16) is favored by the increased dissociation of H_2CO_3.

CONCLUSIONS

The deep upflow of chloride fluids at Broadlands is focused into East and West Bank production zones. The fluid begins to boil at ≥1500 m and ≥300°C with a preboiling gas content of ≥0.6 mol CO_2. Dilution with marginal steam-heated groundwaters, which have an end-member temperature of about 150°C and contain at least 0.1 mol CO_2, is more common in the East Bank than in the West Bank.

Fluid inclusion evidence indicates that in the past, upflow of the deep fluid was focused to a greater degree beneath the East Bank. Although cold groundwater may have initially been the diluent, boiling resulted in the formation of the steam-heated waters, which subsequently diluted the ascending chloride fluid. With time and as steam-heated waters continued to be generated, this mixing occurred deeper in the system as the relatively cool and dense steam-heated waters descended along the margins. This is now particularly evident in the East Bank (to depths >1000 m), resulting in some cooling and illite (± kaolinite and siderite) deposition here in conjunction with the dilution.

Deposition of illite in fractures and pore spaces, largely due to the incursion of diluting steam-heated waters, decreased average permeabilities in the East Bank (Hedenquist, 1983b). This lowering of the permeability may have been the cause of the proposed shift in the focus of upflow towards the West Bank. There is little evidence of dilution and cooling of deep fluids until they reach the shallow levels (500–1000 m depth) and margins of the West Bank portion of the system.

A general assessment of the state of mineral–fluid equilbria indicates that excess enthalpy wells (i.e. two phase feed zones) are not suitable for calculating gas compositions of reservoir liquids. This may be due to non-equilibrium distribution of gases between liquid and vapor in the flashing reservoir. However, liquid feed wells indicate saturation with illite and undersaturation with calcite, plus pyrite–chlorite stability. The common presence of adularia and calcite as fracture fillings may be due to enhanced boiling and gas loss in the fractures as compared with the liquid in the formation.

Cooling of the boiling upflow by mixing with the steam-heated waters is the principal cause of the shift from deep feldspar stability to that of illite. The presence of the relatively cool (~150°C) steam-heated waters over and marginal to the deep upflow is consistent with the distribution of interstratified illite–smectite, as well as marginal kaolinite, siderite and pyrrhotite.

Continued evolution of the Broadlands system may proceed along the lines of that at Waiotapu (Hedenquist and Browne, 1989), where deep incursion of steam-heated water has had a notable effect on the focus of upflow, as well as on the system's mineralogy and isotopic composition.

Mixing of a deep upflow fluid with any cooler, near surface water will greatly affect the alteration mineralogy of the system (Giggenbach, 1984). Therefore, marginal waters must be considered in the development of interpretive models for any system. The occurrence of steam-heated waters in geothermal systems is common, e.g. Hakone, Japan (Oki and Hirano, 1970); Olkaria, Kenya (Leach and Muchemi, 1987); Kawah Kamojang, Indonesia (Kartokusomo *et al.*, 1976); Philippines systems (e.g. Maunder *et al.*, 1982); and New Zealand systems (e.g. Hedenquist and Browne, 1989). For this reason chemical, thermal and mineralogical evidence for their presence should be sought during exploration (e.g. Fe and Mg carbonates are common over the tops of Philippine systems; C. P. Wood, personal communication, 1988). The occurrence of steam-heated waters at shallow levels and on the margins of the system mean they may be easily overlooked. However, dilution trends (even from spring data) will often indicate their presence. Identification of the distribution (and chemistry) of steam-heated waters will assist in defining the zone of deep upflow, as well as identifying potential development-related problems such as casing corrosion and drawdown of marginal waters into the production zone.

Acknowledgements—I acknowledge the efforts of the many people of the Department of Scientific and Industrial Research and the Ministry of Works and Development who collected much of the information presented here over a period of more than 20 years in conjunction with development by the Electricity Corporation. I am grateful to the Electricity Corporation for allowing the publication of their proprietary data. In particular, the detailed petrologic studies of Broadlands cores by Pat Browne and Peter Wood have provided the alteration framework essential for this paper. I thank Werner Giggenbach and Dick Glover for many useful discussions over the course of this study, and Eddie Mroczek and Sharon Thorne for much assistance in the preparation of this paper. This paper has benefited from constructive reviews by Rick Allis, Stefan Arnórsson, Pat Browne, Werner Giggenbach, Dick Glover and Joe Moore.

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System 75,000 years old
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CHANGES IN THERMAL ACTIVITY AT THE TE KOPIA GEOTHERMAL FIELD, TAUPO VOLCANIC ZONE, NEW ZEALAND

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ABSTRACT

The Te Kopia geothermal field has surface manifestations in a zone up to 1.2 km wide that extends for about 3 km along the Paeroa Fault scarp. This fault is normal, has a steep dip, and is still active, with displacements that total 450 m in the Te Kopia area. The fault continues to have an important control on the hydrology of the geothermal field, both by producing steep terrain east of its trace, but also because its successive movements have triggered landslides, hydrothermal eruptions, and variations in the piezometric surface.

Changes that have occurred during the lifetime of the system (>75,000 years) are evident from the geological record and direct observations. For example, beginning in about November 1993, three areas in the north-west part of the field have changed thermally. Temperature surveys at 1.0 m depth in January, February and March 1994 show the areas affected are 10,000 m^2 in total. Vegetation has died, and a vigorously discharging fumarole and then a mudpot formed at one (Murphy's Hill). Petrographic and field evidence of hydrothermal alteration, and fluid inclusion geothermometry, show that the block east of the Paeroa Fault has been upthrown by at least 315 m ± 5 m, exposing reservoir rocks that were once within the Te Kopia reservoir. These are now being altered by steam discharging from this still very active geothermal system.

INTRODUCTION

The Te Kopia geothermal field, the north-eastern section of the larger Orakeikorako and Te Kopia geothermal system (Bignall and Browne, submitted) has been little studied, despite two deep (945 and 1250 m) holes having been drilled there in 1965-66. Te Kopia is located 25 km north of Taupo (Figure 1) and 8 km north-east of the surface manifestations at Orakeikorako. It lies astride the Paeroa Fault, a major tectonic feature of the Taupo Volcanic Zone (TVZ; Figure 1), and at the eastern margin of the Maroa Volcanic Center from which voluminous ignimbrite sheets erupted in Quaternary times. At least three of these sheets are now exposed on the eastern upthrown block of the Paeroa Fault where they form a steep scarp 220 m high at Te Kopia. The two drillholes on the west side of the fault scarp (Figure 2), and four at Orakeikorako, encountered the same ignimbrite sequence, and demonstrate that cumulative vertical displacement on the fault has been at least 450 m.

The Paeroa Fault is normal, dips steeply to the west, but may also have had a component of *strike-slip displacement* (Grindley, 1959); it has moved during the past 1800 years (Nairn and Hull, 1986) and its displacement rate over 75,000 years averaged 4 m/thousand years (Keall, 1987). The thermal evolution of Te Kopia is clearly linked to episodes of movement along this fault, and there has long been interplay between the hydrology of the field and faulting, thermal activity, hydrothermal alteration, and the landsliding events which have occurred there.

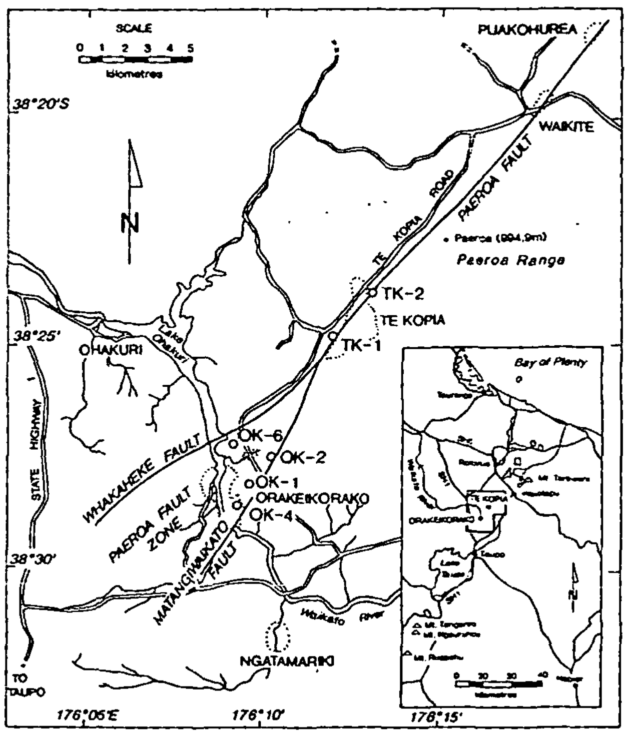

Figure 1: Location of Te Kopia geothermal field in relation to the Paeroa Fault and Orakeikorako. Presently active thermal areas are enclosed by dotted lines. (From Bignall and Browne, submitted).

In this paper we describe some of the changes which have taken place during the lifetime of the Te Kopia system, concentrating mainly on surface manifestations and field evidence. Descriptions of the subsurface geology at Te Kopia and Orakeikorako have been given by Bignall (1994), and the present surface activity at Te Kopia has been described by Bignall and Browne (submitted). Among the few earlier accounts of thermal activity here are those by von Hochstetter (1864), Grange (1937), and Healy (1952, 1974). Sheppard and Klyen (1992) have reported the compositions of some of the fluids now discharging, and Cochrane et al. (1993) and Burns and Leathwick (1993) have studied the types of vegetation present and their distribution with respect to the present thermal regime.

PRESENT DAY SURFICIAL THERMAL ACTIVITY

Thermal manifestations occur over an area extending for about 3 km along the Paeroa Fault Scarp (Bignall, 1994; Bignall and Browne, submitted). The width of the thermally active zone varies up to about 1.2 km in the north (Figures 2 and 3).

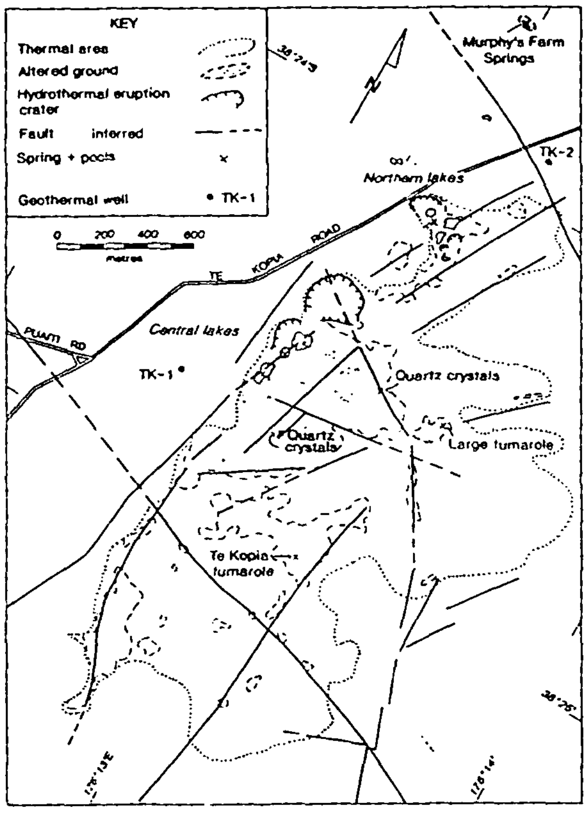

Figure 2: Distribution of main area of thermal activity in the southern part of the Te Kopia field showing distribution of thermally altered ground and location of drillholes; compare with Figure 3. Modifed from Bignall and Browne (submitted).

There are three different types of manifestations:

(1) The most common and widespread are areas of steaming ground accompanied by white clays, disseminated iron oxides, sulfate minerals such as alunite, and silica residue. Also in this category are a few fumaroles discharging superheated steam, including the Te Kopia fumarole itself (Figure 2), located with others along the crest of the scarp but seldom visited. A few smaller steam vents also occur at the foot of the fault scarp.

(2) Small lakes with acid sulfate waters are present in two areas along the foot of the Paeroa Fault scarp (Figure 2). These have low discharge rates but their chloride contents are up to 34 mg/kg (Bignall, 1994). A notable individual feature in the Northern Lakes thermal area is a mud geyser whose periodicity and magnitude largely depends upon the amount of rainfall.

(3) There are several neutral pH springs discharging at the Murphy Farm Springs west of the main thermal area (Figure 3); their flow rates vary from slight to several litres per second at temperatures up to 59°C. The Road Springs (Figure 3) are hotter (75°C) but have discharge rates between 1 and 2 litres per second. None has deposited appreciable amounts of silica but they are probably the surface expression of westward-moving outflows of chloride water that ascends along the fault to the south (Bignall and Browne, submitted).

TEMPORAL CHANGES IN THERMAL ACTIVITY

Field work and petrographic examination of cores recovered from the two drillholes (Figure 2) shows that there have been changes in the magnitude, type and locations of thermal activity at Te Kopia. Since neither well has discharged, except for a brief test period in 1966, the observed and deduced changes in surface activity are not due to any exploitation of the field.

The changes which have occurred are, for convenience, described separately and are considered here as: changes which have taken place in the past 6 months, the past 135 years, and the past 75,000 years. These greatly different scales of resolution are chosen because the rates and magnitude of the changes have varied in both time and space.

Changes in the past 6 months

There have been changes in thermal activity in the north-western part of Te Kopia (Figure 3). These were observed from November 1993 until April 1994. The areas affected by change lies west of the Te Kopia Road and between 500 and 700 m distant from the Paeroa Fault trace (Figure 3). The eastern parts of this area were visited by students making ground temperature and resistivity surveys in September 1993 (Nguyen, 1993; Perez-Ramos, 1993). At that time there was no remarkably high level of thermal activity.

Murphy's Hill: The two long-established mudpots on Murphy's Hill and the nearby chloride springs (Road Springs, Figure 3) seemed to be at the same state of activity as they had been for at least the past 12 years. Sometime in late 1993, however, the following changes started occurring, and these continued until at least April 1994.

(a) A vigorously discharging fumarole formed on Murphy's Hill, a few meters south west of the two long-established mud pots (Figures 2 and 3). In January and February 1994 this was discharging a high volume of gas and very viscous mud. Ground "thumping" was felt up to 100 m away on occasions (M. Murphy, pers. comm.). By late March the mud was less viscous and its surface was within 20 cm of the lip of its vent; ground vibrations had decreased. Hot mud spattered the surround, and all grass within 13 m of the vent had died. Kanuka trees nearby, up to 3 m high, were dying.

(b) Temperatures measured at depths of 0.2 and 1.0 meters changed. Three thermal surveys of the Murphy's Hill area were made: on January 22, February 15 and March 21, 1994, using a thermocouple and meter.

(i) Measurements made on January 22, after vegetation dieback began, outlined an area of above-ambient temperature extending over 2700m^2 (Figure 4). Temperatures were highest in the 1.0 m deep holes closest to the new fumarole, with the 80° isotherm

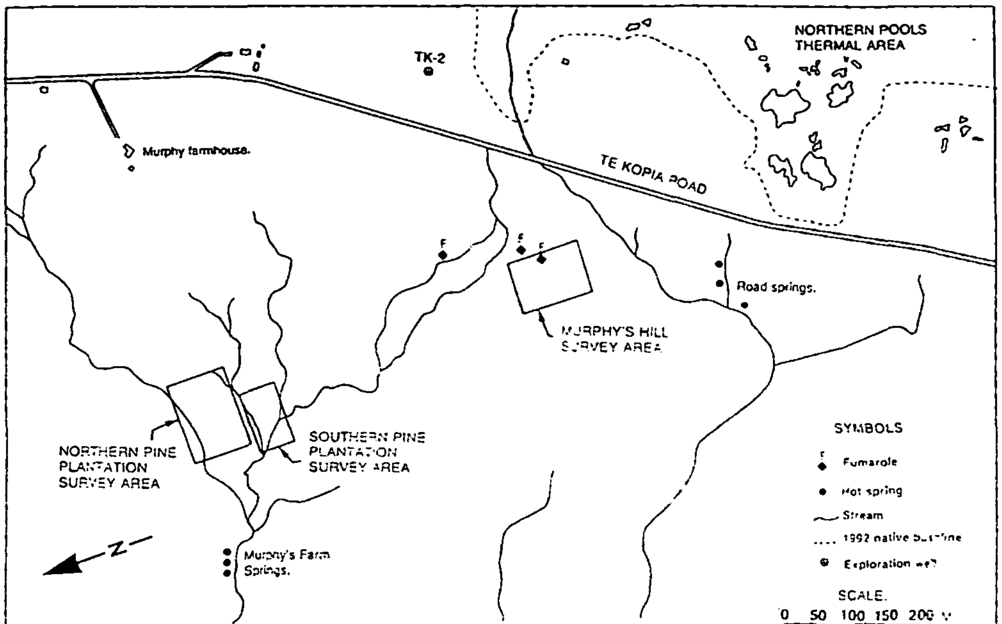

FIGURE 3. MAP OF THE NORTHERN SECTION OF THE TE KOPIA GEOTHERMAL FIELD SHOWING MAJOR EXISTING THERMAL FEATURES AND THE AREAS THAT HAVE UNDERGONE RECENT THERMAL CHANGE.

being on average 20 m distant from it. Two smaller areas with temperatures above 60° were located 30 m and 55 m to the north-west of the fumarole. These have no detectable mass discharge but are also characterised by their recently dead pasture.

(ii) The ground temperature survey made on February 15 extended to the south and west of that measured the previous month. It showed that the isotherm pattern then was very similar to that measured on January 22 but the three hottest areas had each increased in size by several meters, mainly in a north-easterly direction. The maximum temperature in the western thermal high had, however, cooled from 85° to 79° and the central one from 73° to 62°. By contrast, ground temperatures directly to the north-east of the formerly hottest survey holes had increased from 5 to 12° in the 25 days between the two surveys (Figure 5).

(iii) The survey on March 21 showed an overall cooling pattern. This is apparent on all the margins of the area surveyed, and near to the new fumarole where some temperature stations had cooled by 10° to 20° (Figure 6). One station, which 34 days earlier was at 106°, had cooled by 53°. The only temperature increases occurred near to where maxima (63° to 66° and 71° to 78°) were measured on February 15, at a station between them (62° to 67°) and a station close to the vent (71 to 77°C).

The changes in ground temperatures at Murphy's Hill show no simple pattern. Between January 22 and February 15, heating dominated overall, but between February 15 and March 21 almost the whole area had cooled. However, there are stations and small areas where the reverse occurred and some stations showed wide fluctuations in temperature, both increases and decreases. During the survey period the two long-established mudpots on Murphy's Hill and the nearby chloride springs showed no change in their levels of activity or temperatures of discharge. Steaming ground 50-100 m north west of Murphy's Hill also appeared to remain the same.

Pine Plantation: Two areas totalling 7200 m^2 covered by long grass and pine seedlings (Figure 3) showed signs of thermal stress in late 1993. By January 1994 the two areas (southern and northern pine plantations) had temperatures at 1.0 m depth that showed ellipsoid-shaped isothermal patterns whose longer axes were aligned in ESE (southern pine plantation) and NE (northern pine plantation) directions. The smaller southern area had maxima of 52° and 48°C about 33 m apart on January 23. By February 16, the two areas of thermally-stressed vegetation had increased to about 8000 m^2, and the southern plantation had maxima that had increased by 5° (to 57°) and 17° (to 66°); temperatures at 12 of the 13 stations common to the two surveys had cooled to between 51° and 63°, and 10 of the 11 other survey stations had cooled by between 1° and 6°C. Only the most south-easterly station had heated (by only 1.4°) between the two surveys.

The northern pine area had 4 thermal maxima (of 67°, 85°, 86° and 59°) on January 23, aligned in a north-easterly direction and extending over 185 m. By February 16 the three westernmost of these maxima had cooled to 64° (reduced by 3°), 81 (-4°) and 83° (-3°) but the easternmost one had heated to 63° (+4°). Surrounding stations showed slight temperature changes (4.5° to 6°), with 7 recording cooling and 20 heating. In the next 34 days the 4 maxima had again changed, from west to east, by -2°, -5°, +2° and -4°. Cooling dominated in the area overall with 26 other stations recording a reduction in temperature by between 1° and 6°, but only 6 centrally-located stations became hotter.

The changes in thermal activity observed at Te Kopia over the past 6 months are not great in magnitude; indeed, if they had occurred within the main area of thermal activity (Figure 2) they would probably not have been noticed. Their occurrence in farmland made them obvious. However, any changes in natural thermal activity are noteworthy (especially to the farmer) and reflect subsurface perturbations to the thermal regime at

Te Kopia. The area is tectonically active and lies literally in the shadow of the Paeroa Fault Scarp, which strikes in a north-east direction. However, north-west striking faults, albeit of much lesser offset, also occur at Te Kopia (Keall, 1987; Bignall and Browne, submitted). One has an inferred trace that extends through the newly formed hot ground in the pine plantations. On 28 and 29 November 1993, the Te Kopia area was affected by about 100 shallow focus earthquakes; the two largest had magnitudes of 4.3 and 4.5 (B. Scott, pers. comm.), and several were felt in the Murphy farmhouse (Figure 3). The epicentre of these earthquakes is not known but it seems it was within the Te Kopia area itself. There is no direct evidence linking these earthquakes to the onset of the thermal changes described but it is possible that they affected the shallow subsurface hydrology of the northern part of the field. Past fluctuations in the level of thermal activity in this area are recorded by the presence of small patches of steam-altered ground. Some are now at ambient temperatures but one in the pine plantation testifies to an earlier period of thermal activity here.

Alternatively, the changes observed may be only a response to the low rainfall experienced in 1993. Data kindly made available by the National Institute of Water and Atmospheric Research for the Ngakuru Station, 10 km to the north west, show that 1029 mm of rain fell there in 1993 compared with an annual mean of 1193 ±132 mm. That year was, in fact, the driest year at Ngakuru for the past ten years; it is possible that the reduced volume of water runoff from the Te Kopia scarp has allowed these small thermal areas described to heat as the groundwater table descended.

Changes in the past 150 years

Evidence for changes in the intensity and extent of surface thermal activity since 1859 is provided by: (1) the few descriptions made by scientists visiting the area, starting with von Hochstetter (1864) in 1859; (2) comparing the levels and distribution of activity by interpreting aerial photographs made in 1948, 1984, 1991, 1992.

Von Hochstetter (1864) did not map the extent of thermal activity but pointed out the dangers from landslides being triggered by earthquakes. He described the mud geyser, still active today, and apparently in the same state, and reported vigorous steam discharge from the Te Kopia fumarole itself. There is some doubt as to which fumarole he referred to as there are two large fumaroles now discharging on the crest of the scarp. Von Hochstetter made no mention of the presence of sinter or any pools with clear water, which probably indicates that chloride springs were not then discharging.

Grange (1937) reported briefly on the Te Kopia geothermal area, based on his field work in 1929. Unfortunately he made no map, but there is nothing in his account which implies that conditions were greatly different then than they are in 1994. Healy (1974) published the first map showing the extent of thermal activity and the distribution of some of the main discharge features there; his map was mainly a photogeological interpretation and clearly shows some of the craters and the Central and Northern lakes (see Figure 2). We conclude, therefore, that there is no evidence from the few written accounts available that thermal activity at Te Kopia has changed appreciably in intensity or location during the past 135 years. However, there is an unsubstantiated suggestion that a small hydrothermal eruption occurred in the Northern lakes area in 1886 contemporaneous with the basaltic eruption from Mt Tarawera. The two mudpots on Murphy's Hill enlarged in about 1971, but there is no documentation of this event.

Preliminary interpretation and comparison of thermal activity on aerial photographs taken in 1948, 1984, 1991 and 1992 show several differences in the extent and distribution of altered ground and thermally-stressed vegetation in the northern part of the Te Kopia area.

There have also been changes in the chloride contents of the largest pond in the Central lakes region (Figure 2). Grange (1937) reported it as containing 113 mg/kg Cl; by 1965 this had increased to 142 mg/kg Cl (Mahon, 1965), but analyses made in 1993 gave values of less than 33.6 mg/kg Cl (Bignall and Browne, submitted). A small amount of ascending chloride water therefore still reaches the surface in the low elevations of the Central lakes, but the proportion of chloride water relative to steam condensate and meteoric water fluctuates. Not enough alkali chloride water reaches the surface in this area, however, to cause silica sinter to precipitate.

Changes in the past 75,000 years

Evidence for changes in near-surface geothermal activity at Te Kopia is as follows (Bignall, 1994; Bignall and Browne, submitted):

(1) The occurrence of silica sinter in the Central Lakes area, but about 5 m above the present lake levels, which C^{14} dating shows deposited 3026 ±43 years BP. Alkali chloride waters were therefore discharging here at that time.

(2) The presence of at least two separate deposits of hydrothermal eruption breccias, although it is not certain that either derive from craters in the Northern or Central Lakes areas (Figure 2). The relationships between the eruption breccias and interbedded tephras indicate that two eruptions occurred between 186 AD and 22,700 years ago.

(3) Extensive deposits of breccias produced by large landslides. Tephrochronology indicates that these occurred before and after a 22,700-year-old volcanic event at Lake Taupo and since 186 AD. Occasional clasts in these landslide breccias are hydrothermally altered (including mordenite, quartz and adularia), proving that geothermal activity was taking place on the scarp before these landslides occurred. It seems most likely that episodic movement on the Paeroa Fault triggered the landslides.

(4) The widespread overprinting of hydrothermal alteration minerals in rocks exposed on the fault scarp. For example, rocks originally altered in the subsurface to a quartz-illite assemblage are now partly replaced by kaolinite. In the most strongly overprinted rocks, the products are a mixture of quartz, pug, kaolinite, cristobalite and alunite (Bignall, 1994).

(5) The presence of rocks now at the surface containing hydrothermal minerals that formed deep (>250 m) within a geothermal reservoir; for example, adularia, illite and chlorite.

(6) The occurrence of euhedral quartz crystals on the ground in two areas east of the Paeroa Fault. These contain liquid-rich fluid inclusions that homogenise at 196 ±11°C and 188 ±15°C. Consideration of the boiling temperature versus depth conditions indicate that one set of quartz crystals grew at depths at least 170 m below ground surface (trapped fluids are of low apparent salinity, < 0.4 wt % NaCl equivalent). Crystals now occur on the upthrown fault block at elevations 145 ±5 m above the floor of the Te Kopia Valley. These crystals have thus been uplifted by at least 315 m. By similar reasoning, the other set of quartz crystals, now 180 m above the valley floor, have ascended at least 300 m since their formation.

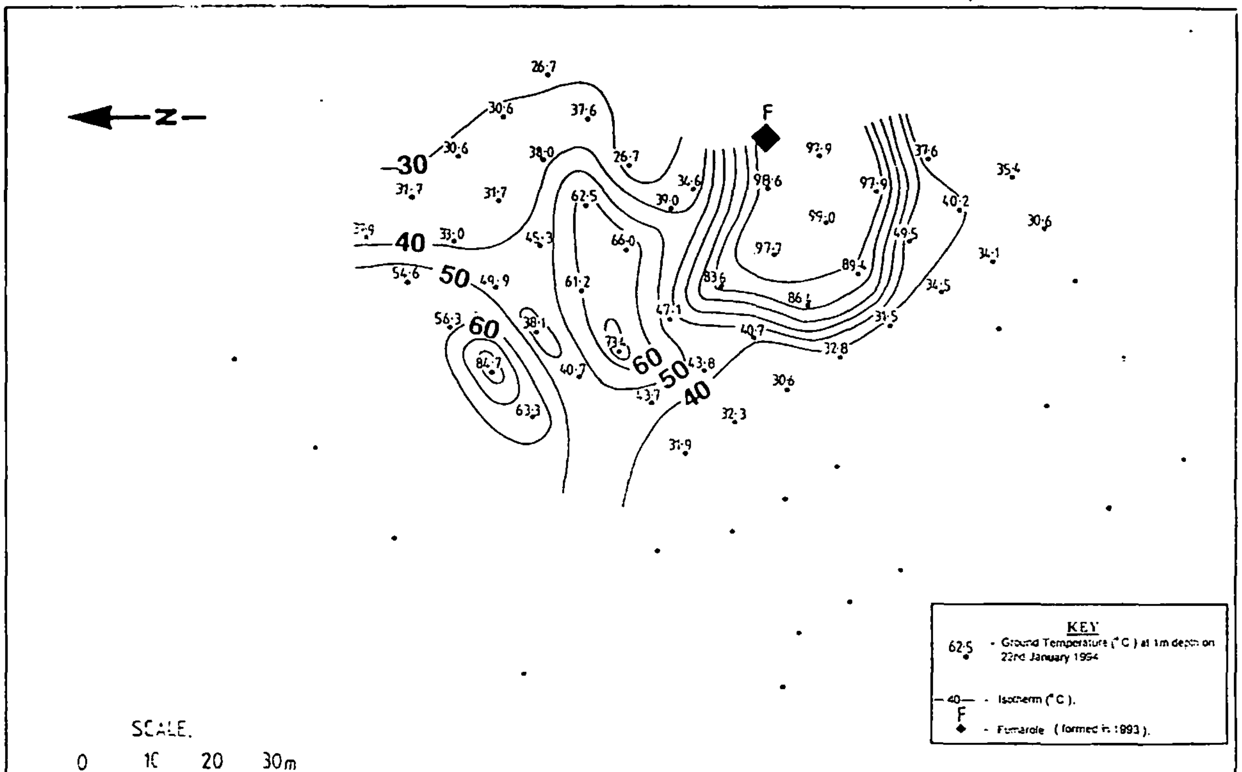

FIGURE 4. Contoured temperature profile map of Murphy's hill area, showing ground temperatures at 1m depth on 22nd January 1994.

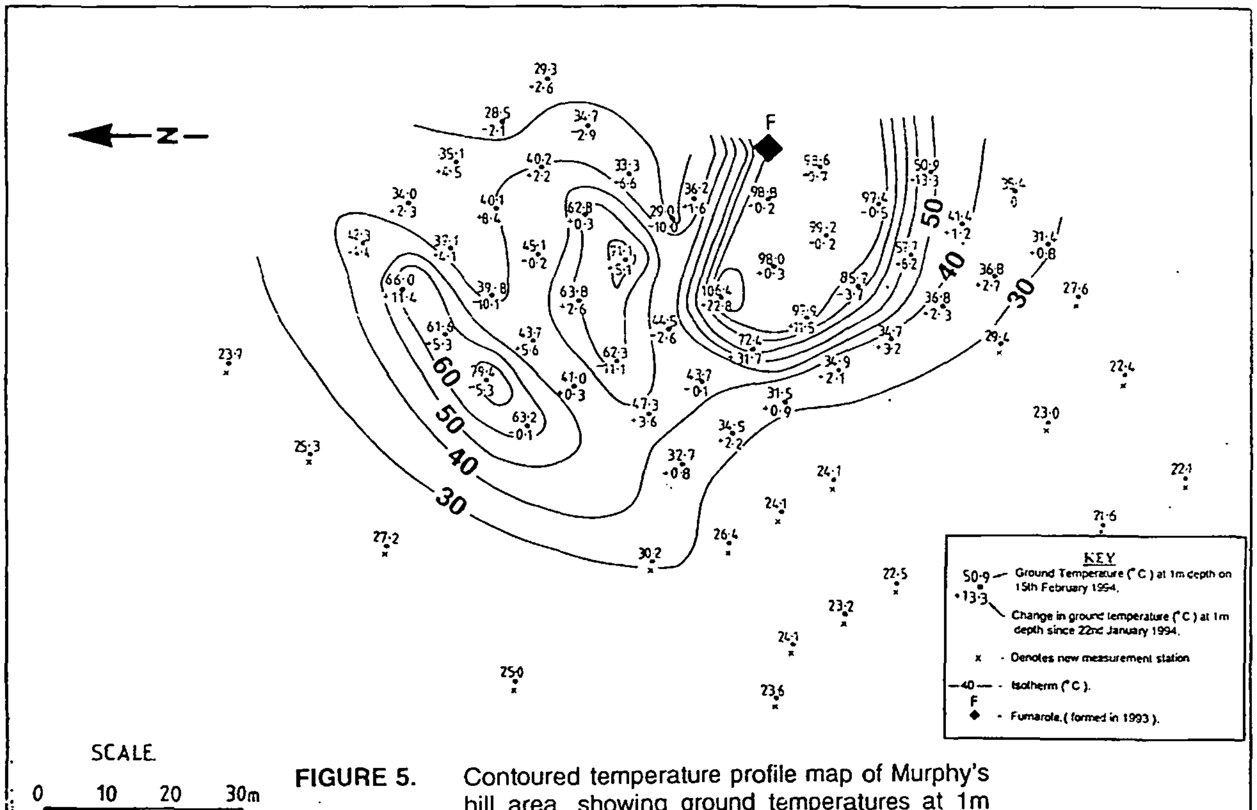

FIGURE 5. Contoured temperature profile map of Murphy's hill area, showing ground temperatures at 1m depth on 15th February 1994 and also changes that have occurred since 22nd January 1994.

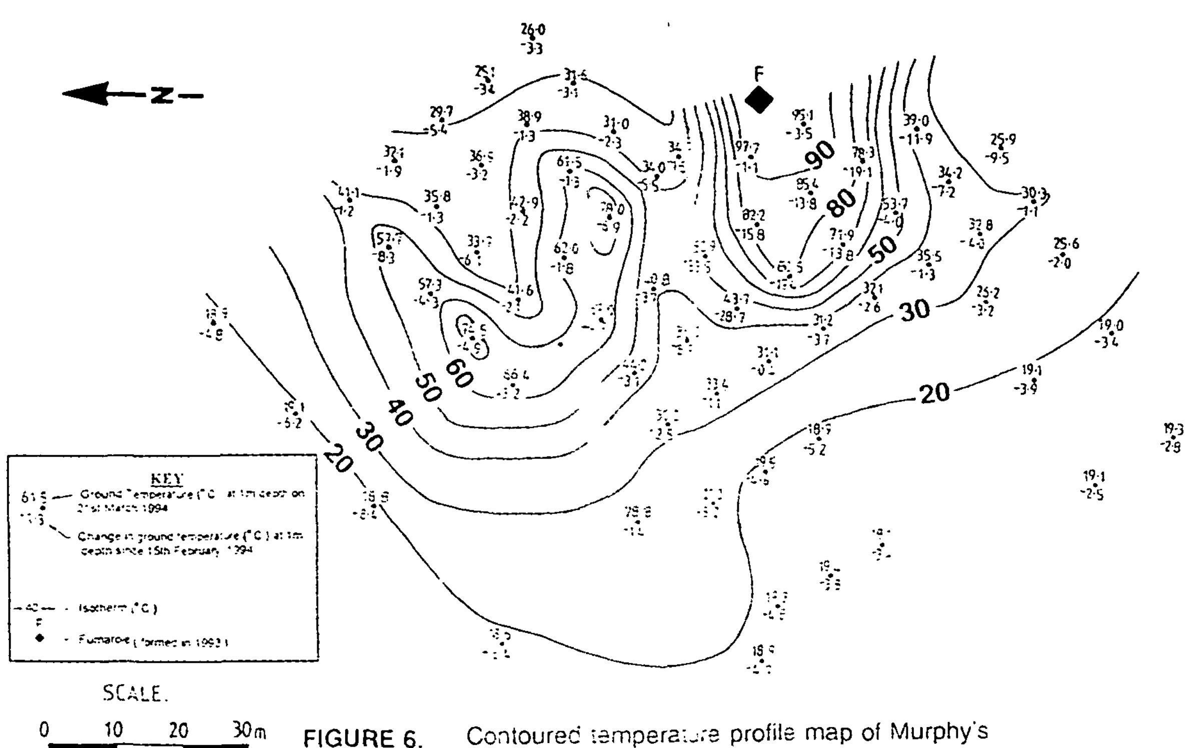

FIGURE 6. Contoured temperature profile map of Murphy's hill area, showing ground temperatures at 1m depth on 21st March 1994 and also changes that have occurred since 15th February 1994.

CONCLUSIONS

Evidence and observations show that surface thermal activity at Te Kopia has changed constantly during the lifetime of the system, believed to be at least 75,000 years but possibly 15,000 years (Bignall, 1994). Many of these changes are slight and have gone unrecorded, but others have left their marks in the geological record. The location of the Te Kopia field on a major active tectonic feature (Paeroa Fault) has allowed interplay between hydrology and fault movement.

Most major displacements on the fault resulted in a change in hydrology of the geothermal field, probably caused landsliding, and perhaps some movements triggered hydrothermal eruptions. Because of the sensitivity of a geothermal system in such steep terrain, short and long term climatic changes also probably affected surface thermal activity, for example, long term and annual differences in rainfall.

Progressive uplift of the eastern block of the Paeroa Fault has now exposed rocks once at least 300 m below ground surface in the bowels of the geothermal reservoir. Their alteration records these changes through textural overprinting, and provides information about temperatures and fluid types then present in the former reservoir.

In the past 3000 years, the piezometric surface has been descending so that chloride waters now mostly discharge only in the most western part of the field, hundreds of meters distant from where they did so formerly. Drilling shows that temperatures in the present reservoir exceed 240° at a depth of 1200 m. The Te Kopia field is still very active despite its longevity.

ACKNOWLEDGEMENTS

We thank Environment Waikato for a grant to help cover field costs. We also thank J. McLeod, M.P. Hochstein and S.F. Simmons for their interest in this work. Mr M. Murphy provided important detail about recent changes in thermal activity on his farm. We also thank Mrs Mary Weston for her assistance in producing this paper at short notice.

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