A Guide to Federal Funds for Geothermal Energy Projects

What is it?

Are you –

- *A leaseholder or owner of property over a geothermal energy reservoir?*
- *A farmer, commodity distributor or businessman planning to use geothermal heat for food drying or for the production of gasahol?*
- *A publically-owned or municipal utility or cooperative seeking additional electric production from an alternative energy source?*
- *A small business wishing to incorporate geothermal heat in a business venture?*
- *A state agency desiring to conserve energy and promote alternative energy resources?*
- *An urban or rural government agency, Indian Tribe, or business considering the use of geothermal heat in a venture to conserve energy or promote economic growth?*
- *A company planning to use geothermal heat in an economically depressed area?*

Then you should be interested in reviewing the contents of this brochure if you want to consider Federal assistance in funding your project.

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Purpose

The Department of Energy (DOE) is carrying out a geothermal energy commercialization program to assist you in establishing projects that develop geothermal reservoirs or projects that use geothermal energy. This brochure is intended to acquaint you with those existing Federal funding programs that may be available to finance a geothermal energy project. Requirements and eligibility for Federal funds periodically change and therefore the information in this brochure may not be completely up to date. Additionally, new funding programs and changes to existing programs are being considered by Congress. This brochure will be updated whenever significant changes occur.

Federal Tax Benefits

Geothermal energy was made the target of special tax benefits designed to stimulate commercial investment in projects using this alternative energy resource. These tax benefits include the expensing of intangible drilling costs and a depletion allowance for those projects that develop geothermal energy reservoirs, and investment tax credits for those projects that use geothermal energy.

Under most conditions, these Federal tax benefits may be taken together with certain other forms of Federal funding assistance outlined in this brochure. The financial terms of your specific geothermal project should be discussed with the nearest Internal Revenue Service office, or your tax advisor, to determine whether the use of Federal funding assistance will interfere with your use of these tax benefits.

Types of Assistance Available

Federal funds that may be available to assist you in financing a geothermal energy development or utilization project consist of the following general types:

- Formula grants – allocations of Federal funds to states or their subdivisions made in accordance with a distribution formula prescribed by law or regulation. These funds are then distributed by a state agency for projects or purposes which meet program requirements. Grants of money received from this source are not required to be repaid and therefore competition for available funds is high.

MINARY

- Project grants — allocations of funds by a Federal agency for a specific project or purpose. Funds received from this source are usually not repaid and competition is high.
- Direct loans — Funds made available through a loan by a Federal agency directly to an applicant that meets program requirements. Direct loans may not require the payment of interest or may provide funds at below-market interest rates. Funds received from this source are expected to be repaid.
- Guaranteed/Insured loans — Funds made available through a commercial loan or through a loan made by the Federal Financing Bank. A Federal agency guarantees payment of principal and interest if the borrower defaults. Guarantees are made only when there is reasonable expectation that the borrower can meet the loan repayment schedule.

Who Qualifies?

You may, if you can meet program requirements. Individuals and organizations of all types may qualify for one or more program. The programs summarized in this brochure can provide assistance to farmers, urban and rural agencies, individuals, small and large businesses, school districts, hospitals, Indian Tribes, Alaskan natives, economically disadvantaged individuals, utilities, municipal agencies, electric cooperatives, natural resource developers, and others. Federal eligibility requirements differ among the programs and you are encouraged to discuss your specific project with the program's Washington, D.C. contact point identified in this brochure.

How Much Money is Available?

Federal funding of eligible projects varies for each program. For highly competitive grant programs you might receive only about 20% of the project's construction cost. Guaranteed loan programs can cover from 75% to 100% of a project's total cost. A few Federal agencies place maximum limits on the amount of assistance available to an individual applicant. Some Federal agencies permit the same project to be partially financed by one or more other funding sources. In summary, the amount of money that is available can be sufficient to fund a significant portion of your geothermal project if you are willing to seek a guaranteed loan and are able to establish reasonable assurance that the loan will be repaid.

PRELIM

How Long Does It Take?

The speed at which your application can be processed by the responsible Federal agency depends upon the completeness of your submission. Generally, a decision can be made within one to six months after your application is accepted for processing. To be accepted your application must be complete, must include all necessary information, and must conform to requirements established by the responsible Federal agency. By calling the agency's office in Washington, D.C., you can receive instructions and guidance in preparing an application.

Must the Project Contain Geothermal Energy?

To qualify for assistance under DOE's Geothermal Loan Guaranty Program, it is necessary that your project include either the development of a geothermal reservoir or the use of geothermal heat. Only DOE's Geothermal Loan Guaranty Program is authorized to approve projects aimed at developing a geothermal reservoir or projects that include new or innovative geothermal technology. However, DOE will not favorably consider projects that are limited to geothermal exploration (i.e., wild catting).

To quality for assistance under other Federal funding programs, it is necessary that your project first meet certain geographic, social, economic or community objectives. If your project is aimed at one or more of these objectives and it also includes the use of geothermal energy, then your project is eligible for consideration under a variety of programs. Other Federal agencies will not favorably consider projects that include geothermal reservoir exploration and development, or the use of unproven technology.

What's Required?

To obtain assistance under any of the Federal funding programs listed in this brochure you will be required to submit information outlining the projects cost, management, milestones, economics, market and technology. Other information describing the projects' ability to meet geographic, social, economic or community objectives will also be required. For geothermal projects you will be asked to include descriptions and characteristics of the reservoir you propose to develop or use. The quality of information you present will govern the speed at which the responsible Federal agency can reach a final decision on your application.

Other assistance requirements including equity, recourse, interest rate, personal guarantees, guaranty fees, collateral, patents, proprietary information, or equal opportunity compliance differ among Federal programs. Each program's office in Washington, D.C., can describe those requirements imposed by law or regulation. Advance knowledge of those requirements may be of value in deciding which Federal program is best suited to your needs.

How to Apply

Each Federal agency responsible for a funding program has filing procedures that it follows in considering applications for financial assistance. To assist you in gathering information on procedures for filing an application and for complying with any deadlines for its submission, this brochure contains the address and telephone number of each program's Washington, D.C. office. Specific information and guidance on your projects eligibility and on filing an application is available from these offices.

Federal Assistance Programs

The information presented for each of the following financial assistance programs is intended to provide you with a quick overview of the program's scope only for planning purposes. Because of shifting requirements and priorities you should not prejudge your project's eligibility for Federal assistance. Those programs which appear to be suited to your needs should be discussed with the Washington, D.C. office of the appropriate agency.

U.S. Department of Agriculture

Farmers Home Administration

Program: Business and Industrial Loans

Eligibility: Any legal entity, Indian Tribe, local government agency located in rural areas

Purpose: To assist in financing business and industry

Type of Assistance: Guaranteed and Insured Loans.

Assistance Considerations:

- Applicants provide a minimum of 10% equity.
- Loan maturity limited to 30 years for permanent fixtures, to 15 years for equipment and machinery, and to 40 years for community facilities.

Deadlines for Applying: None

Range of Assistance Awarded: $11,000 to $33,000,000

Maximum Load Size Authorized: No Limit

Fm HA Decision Time: 60 to 90 Days

Information Contact:
Washington, D.C. Telephone: (202) 447–3479

Program: Community Facilities Loans

Eligibility: State and local government agencies, Indian Tribes, not–for–profit corporations located in rural areas

Purpose: To assist in financing essential services, including industrial parks

Type of Assistance: Insured loans with 5% interest rate.

Assistance Considerations:

- Facilities must be available for public use.
- Loans made for projects serving largest number of rural residents.

Deadlines for Applying: None

Range of Assistance Awarded: $1,600 to $18,000,000

Maximum Individual Loan Size Authorized: No Limit

Fm HA Decision Time: 30 to 90 days

Information Contact:
Washington, D.C. Telephone: (202) 447–7667

Rural Electrification Administration

Program: Rural Electrification Loan Guarantees

Eligibility: Electric cooperatives, public utility districts, power companies, municipalities, and power suppliers serving rural areas

Rural Electrification Administration (cont'd)

Purpose: *To provide reliable electric service to rural persons*

Type of Assistance: Guaranteed and Insured Loans

Assistance Considerations:

- Loan maturity up to 35 years
- Equity up to 30% may be required
- REA approval of loan terms and conditions

Deadlines: None

Range of Assistance Awarded:
$250,000 to $40,000,000 – Insured Loans
$10,000,000 to $1,400,000,000 – Guaranteed Loans

Maximum Individual Loan Size Authorized: No Limit

REA Decision Time: 3 to 6 Months

Information Contact:
Washington, D.C. Telephone: (202) 447–5606

U.S. Department of Commerce

Economic Development Administration

Program: Public Works and Development Facilities

Eligibility: State and local government agencies, Indian Tribes, and nonprofit organizations in geographic areas where economic growth is lagging

Purpose: To assist in the construction of public facilities needed for long term economic growth

Type of Assistance: Project grants

Assistance Considerations:

- Basic grant may be up to 50% of project cost
- Severely depressed areas may receive up to 80% of project cost
- Indian Tribes eligible for 100% assistance

Deadlines: None

Range of Assistance Awarded: $5,000 to $7,138,000

Maximum Individual Grant Authorized: No dollar limitation

EDA Decision Time: Within 90 days of application acceptance

Information Contact:
Washington, D.C. Telephone: (202) 377–5265

U.S. Department of Commerce

Economic Development Administration

Program: Business Development Assistance

Eligibility: *Any individual, private or public corporation, Indian Tribe, profit corporation*

Purpose: To provide financial assistance to businesses that expand or establish plants in designated areas

Type of Assistance: Direct Loans; Guaranteed/Insured Loans

Assistance Considerations:

- Project must be sited in geographically depressed area
- Financial assistance is otherwise not available
- Applicant's willingness to contribute equity beyond the minimum requirement

Deadlines: None

Range of Assistance Awarded: $260,000 to $5,200,0

Maximum Individual Assistance Authorized:
May be revised by Congress

EDA Decision Time: *3 to 4 months with complete supporting documents*

Information Contact:
Washington, D.C. Telephone: (202) 377–260

U.S. Department of Energy

Program: Energy Conservation for Institutional Buildings

Eligibility: State energy agencies

Purpose: To assist local government in financing energy conservation measures for schools hospitals and buildings

Type of Assistance: Formula Grants

Assistance Considerations:

- Not available for buildings constructed after April 20, 1977.
- Assistance matched by grantee on a formula basis.

Deadlines: Annual submission. Contact state energ agency for dates.

Range of Assistance Awarded: Not Available

DOE Processing Time: 30 to 60 Days

Information Contact:
Washington, D.C. Telephone: (202) 252–23

U.S. Department of Energy

Program: Geothermal Loan Guarantees

Eligibility: Any company, utility, person, state or local government agency, Indian Tribe

Purpose: To assist in financing projects to develop and use geothermal energy

Type of Assistance:. Loan Guarantees

Assistance Considerations:
- Borrower required to provide 25% equity
- Loan maturity limited to 30 years or useful life of key project components
- DOE approval of loan terms and conditions

Deadlines for Applications: None

Range of Assistance Awarded:
$1,800,000 to $29,000,000

Maximum Individual Guaranty Authorized:
Up to $100 million per project.

DOE Decision Time: 6 to 9 months with complete supporting documents

Information Contact:
Washington, D.C. Telephone: (202) 633–8760

U.S. Department of Housing and Urban Development

Program: Mortgage Insurance – Land Development and New Communities

Eligibility: Developers of large subdivisions or new communities

Purpose: To insure lenders against loss on mortgage loans

Type of Assistance: Guaranteed Loans

Assistance Considerations:
- Maximum guaranty limited to percentage based on HUD estimates
- Loan maturity up to 10 years
- Project soundness

Deadlines: Established on a case–by–case basis

Range of Assistance Awarded: Not Available

HUD Decision Time: 3 to 9 months depending on sponsors preparation

Information Contact:
Washington, D.C. Telephone: (202) 755–6887

U.S. Department of Housing and Urban Development

Program: Mortgage Insurance – Hospitals

Eligibility: Facility licensed by state or local government agency

Purpose: To assist in financing the construction or rehabilitation of hospitals

Type of Assistance: Guaranteed Loans

Assistance Considerations:
- Maximum mortgage amount may not exceed 90% of estimated replacement cost
- State certification as to need for facility
- Loan maturity up to 25 years

Deadlines: Not Applicable

Range of Assistance Awarded: Not Available

HUD Decision Time: Processing time depends on the sponsors preparation

Information Contact:
Washington, D.C. Telephone: (202) 755–9280

Program: Mortgage Insurance – Nursing Homes and Intermediate Care Facilities

Eligibility: Investors, builders, developers, and private nonprofit corporations or associations licensed or regulated by the state

Purpose: To assist in financing the construction or rehabilitation of nursing homes and intermediate care facilities

Type of Assistance: Guaranteed Loans

Assistance Considerations:
- Guarantee limited to 90% of value of physical improvement.
- Current maximum interest rate is 9 ½% plus ½%.
- Loan maturity is up to 40 years.

Deadlines for Application: Established on a case–by–case basis.

Range of Assistance Awarded: Not Available

HUD Decision Time: Dependent on sponsor's application preparation

Information Contact:
Washington, D.C. Telephone: (202) 755–9280

U.S Department of Housing and Urban Development

Program: Indian Community Development

Eligibility: Indian Tribes otherwise eligible for assistance under the Indian Self-Determination and Education Assistance Act or under the State and Local Assistance Act

Purpose: To assist Indian Tribes and Alaska Natives in the development of viable communities and expand economic opportunities

Type of Assistance: Project Grants. No formula and matching requirements.

Assistance Considerations:

- Projects must principally aid persons of low and moderate income.

Deadlines for Application Submission:
HUD established deadlines are published in the Federal Register.

Range of Assistance Awarded: $43,000 to $1,714,532

HUD Decision Time: Target time is 45 days for preapplications and 45 days for full applications.

Information Contact:
Washington, D.C. Telephone: (202) 755–6092

Program: Urban Development Action Grants

Eligibility: Distressed cities and urban counties which meet criteria specified in regulations (24 CFR Part 570.452)

Purpose: To alleviate physical and economic deterioration through economic development and neighborhood revitalization

Type of Assistance: Project Grants

Assistance Considerations:

- More favorable consideration given to projects that include funds from the state or other public entities.
- Assistance is provided for a project that can be completed in about 4 years.

Deadlines for Application Submission:
Metropolitan cities and urban counties in January, April, July and October. Small cities in February, May, August and November.

Range of Assistance Awarded:

Metro cities	$85,000 to $13,500,000
Small cities	$77,700 to $5,700,000

HUD Decision Time: Within 60 to 90 days

Information Contact:
Washington, D.C. Telephone: (202) 472–3947

U.S. Department of the Interior

Bureau of Indian Affairs

Program: Indian Loans – Economic Development

Eligibility: Indians, Alaska Natives, Tribes, and Indian Organizations

Purpose: To promote the economic development of a Federal Indian Reservation

Types of Assistance: Project Grants; Direct Loans; Guaranteed Loans

Assistance Considerations:

- *Funds must be unavailable from other sources under reasonable terms and conditions.*
- *Individual applicants must be a member of a federally recognized tribe and not members of an Indian organization that conducts its own credit program.*
- Funds must be used on or near a Federal Indian Reservation.

Deadlines for Application Submission: None

Range of Assistance Awarded: $100 to over $1,000,000

Maximum Assistance Authorized:
Guarantees limited to 90% of the loan; Grants limited to 40% or $50,000 of the projects cost.

DOI Decision Time: 60 days depending upon completeness of loan application.

Information Contact:
Washington, D.C. Telephone: (202) 343–5875

Small Business Administration

Program: Small Business Loans

Eligibility: *Any small business which is independently owned and operated, and is not dominant in its field*

Purpose: To assist small businesses, including agricultural enterprises, in obtaining credit

Type of Assistance: Direct Loans; Guaranteed Loans

Assistance Considerations:

- *Funds must be unavailable from commercial sources under reasonable terms and conditions.*
- *Funds cannot be used to pay off an unsecured creditor who is in a position to sustain loss.*
- Applicant must meet SBA size standard for small business.

Deadlines for Application Submission: None

Range of Assistance Awarded:
Guaranteed Loans $1,800 to $500,000;
Direct Loans $1,000 to $350,000.

SBA Decision Time: Within 3 to 60 days after application acceptance.

Information Contact:
Washington, D.C. Telephone: (202) 653–6570

Is More Information Available?

More detailed information on each program is available from the agency's office in Washington, D.C. You can get information on agency regulations, filing procedures and forms, and other general instructions. Agency personnel can also provide advice on eligibility and discuss matters specific to your geothermal project and its financing.

Unsolicited Proposals

In order to meet its energy objectives, DOE encourages any organization or individual to submit imaginative and innovative research or investigation proposals that will assist in the development of energy resources. When you initiate a proposal that is not in response to a formal DOE request, the proposal is considered to be unsolicited. DOE may accept and fund geothermal energy unsolicited proposals to carry out research, development and commercial demonstrations. In evaluating an unsolicited proposal, DOE considers whether it will duplicate work underway or contemplated by DOE, or whether the work proposed has been previously determined to have no merit or value, and whether funds are available to carry out such work. You are urged to informally consult with DOE, prior to preparing a written unsolicited proposal, to determine DOE's interest in your planned work. Funding for unsolicited proposals is highly competitive and *prospective proposers have found informal discussions* with DOE geothermal staff to be of value in reducing paperwork and minimizing lost time. DOE geothermal staff are available for consultation by contacting:

Division of Geothermal Energy,
RA–231
Office of the Assistant Secretary for
Resource Applications
U.S. Department of Energy
Washington, D.C. 20461
(202) 633–8760

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PRELI

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Must the Project Contain Geothermal Energy?

To qualify for assistance under DOE's Geothermal Loan Guaranty Program, it is necessary that your project include either the development of a geothermal reservoir or the use of geothermal heat. Only DOE's Geothermal Loan Guaranty Program is authorized to approve projects aimed at developing a geothermal reservoir or projects that include new or innovative geothermal technology. However, DOE will not favorably consider projects that are limited to geothermal exploration (i.e., wild catting).

To quality for assistance under other Federal funding programs, it is necessary that your project first meet certain geographic, social, economic or community objectives. If your project is aimed at one or more of these objectives and it also includes the use of geothermal energy, then your project is eligible for consideration under a variety of programs. Other Federal agencies will not favorably consider projects that include geothermal reservoir exploration and development, or the use of unproven technology.

What's Required?

To obtain assistance under any of the Federal funding programs listed in this brochure you will be required to submit information outlining the projects cost, management, milestones, economics, market and technology. Other information describing the projects' ability to meet geographic, social, economic or community objectives will also be required. For geothermal projects you will be asked to include descriptions and characteristics of the reservoir you propose to develop or use. The quality of information you present will govern the speed at which the responsible Federal agency can reach a final decision on your application.

Other assistance requirements including equity, recourse, interest rate, personal guarantees, guaranty fees, collateral, patents, proprietary information, or equal opportunity compliance differ among Federal programs. Each program's office in Washington, D.C., can describe those requirements imposed by law or regulation. Advance knowledge of those requirements may be of value in deciding which Federal program is best suited to your needs.

How to Apply

Each Federal agency responsible for a funding program has filing procedures that it follows in considering applications for financial assistance. To assist you in gathering information on procedures for filing an application and for complying with any deadlines for its submission, this brochure contains the address and telephone number of each program's Washington, D.C. office. Specific information and guidance on your projects eligibility and on filing an application is available from these offices.

Federal Assistance Programs

The information presented for each of the following financial assistance programs is intended to provide you with a quick overview of the program's scope only for planning purposes. Because of shifting requirements and priorities you should not prejudge your project's eligibility for Federal assistance. Those programs which appear to be suited to your needs should be discussed with the Washington, D.C. office of the appropriate agency.

U.S. Department of Agriculture

Farmers Home Administration

Program: Business and Industrial Loans

Eligibility: Any legal entity, Indian Tribe, local government agency located in rural areas

Purpose: To assist in financing business and industry

Type of Assistance: Guaranteed and Insured Loans.

Assistance Considerations:

- Applicants provide a minimum of 10% equity.
- Loan maturity limited to 30 years for permanent fixtures, to 15 years for equipment and machinery, and to 40 years for community facilities.

Deadlines for Applying: None

Range of Assistance Awarded: $11,000 to $33,000,000

Maximum Load Size Authorized: No Limit

Fm HA Decision Time: 60 to 90 Days

Information Contact:
Washington, D.C. Telephone: (202) 447–3479

Program: Community Facilities Loans

Eligibility: State and local government agencies, Indian Tribes, not–for–profit corporations located in rural areas

Purpose: To assist in financing essential services, including industrial parks

Type of Assistance: Insured loans with 5% interest rate.

Assistance Considerations:

- Facilities must be available for public use.
- Loans made for projects serving largest number of rural residents.

Deadlines for Applying: None

Range of Assistance Awarded: $1,600 to $18,000,000

Maximum Individual Loan Size Authorized: No Limit

Fm HA Decision Time: 30 to 90 days

Information Contact:
Washington, D.C. Telephone: (202) 447–7667

Rural Electrification Administration

Program: Rural Electrification Loan Guarantees

Eligibility: *Electric cooperatives, public utility districts, power companies, municipalities, and power suppliers serving rural areas*

Rural Electrification Administration (cont'd)

Purpose: To provide reliable electric service to rural persons

Type of Assistance: Guaranteed and Insured Loans

Assistance Considerations:

- Loan maturity up to 35 years
- Equity up to 30% may be required
- REA approval of loan terms and conditions

Deadlines: None

Range of Assistance Awarded:
$250,000 to $40,000,000 – Insured Loans
$10,000,000 to $1,400,000,000 – Guaranteed Loans

Maximum Individual Loan Size Authorized: No Limit

REA Decision Time: 3 to 6 Months

Information Contact:
Washington, D.C. Telephone: (202) 447–5606

U.S. Department of Commerce

Economic Development Administration

Program: Public Works and Development Facilities

Eligibility: State and local government agencies, Indian Tribes, and nonprofit organizations in geographic areas where economic growth is lagging

Purpose: To assist in the construction of public facilities needed for long term economic growth

Type of Assistance: Project grants

Assistance Considerations:

- Basic grant may be up to 50% of project cost
- Severely depressed areas may receive up to 80% of project cost
- Indian Tribes eligible for 100% assistance

Deadlines: None

Range of Assistance Awarded: $5,000 to $7,138,000

Maximum Individual Grant Authorized: No dollar limitation

EDA Decision Time: Within 90 days of application acceptance

Information Contact:
Washington, D.C. Telephone: (202) 377–5265

U.S. Department of Commerce

Economic Development Administration

Program: Business Development Assistance

Eligibility: Any individual, private or public corporation, Indian Tribe, profit corporation

Purpose: To provide financial assistance to businesses that expand or establish plants in designated areas

Type of Assistance: Direct Loans; Guaranteed/Insured Loans

Assistance Considerations:

- Project must be sited in geographically depressed area
- Financial assistance is otherwise not available
- Applicant's willingness to contribute equity beyond the minimum requiremen

Deadlines: None

Range of Assistance Awarded: $260,000 to $5,200,0

Maximum Individual Assistance Authorized:
May be revised by Congress

EDA Decision Time: 3 to 4 months with complete supporting documents

Information Contact:
Washington, D.C. Telephone: (202) 377–260

U.S. Department of Energy

Program: Energy Conservation for Institutional Buildings

Eligibility: State energy agencies

Purpose: To assist local government in financing energy conservation measures for schools hospitals and buildings

Type of Assistance: Formula Grants

Assistance Considerations:

- Not available for buildings constructed after April 20, 1977.
- Assistance matched by grantee on a formula basis.

Deadlines: Annual submission. Contact state energ agency for dates.

Range of Assistance Awarded: Not Available

DOE Processing Time: 30 to 60 Days

Information Contact:
Washington, D.C. Telephone: (202) 252–23

U.S. Department of Energy

Program: Geothermal Loan Guarantees

Eligibility: Any company, utility, person, state or local government agency, Indian Tribe

Purpose: To assist in financing projects to develop and use geothermal energy

Type of Assistance:. Loan Guarantees

Assistance Considerations:

- Borrower required to provide 25% equity
- Loan maturity limited to 30 years or useful life of key project components
- DOE approval of loan terms and conditions

Deadlines for Applications: None

Range of Assistance Awarded:
$1,800,000 to $29,000,000

Maximum Individual Guaranty Authorized:
Up to $100 million per project.

DOE Decision Time: 6 to 9 months with complete supporting documents

Information Contact:
Washington, D.C. Telephone: (202) 633–8760

U.S. Department of Housing and Urban Development

Program: Mortgage Insurance – Land Development and New Communities

Eligibility: Developers of large subdivisions or new communities

Purpose: To insure lenders against loss on mortgage loans

Type of Assistance: Guaranteed Loans

Assistance Considerations:

- Maximum guaranty limited to percentage based on HUD estimates
- Loan maturity up to 10 years
- Project soundness

Deadlines: Established on a case–by–case basis

Range of Assistance Awarded: Not Available

HUD Decision Time: 3 to 9 months depending on sponsors preparation

Information Contact:
Washington, D.C. Telephone: (202) 755–6887

U.S. Department of Housing and Urban Development

Program: Mortgage Insurance – Hospitals

Eligibility: Facility licensed by state or local government agency

Purpose: To assist in financing the construction or rehabilitation of hospitals

Type of Assistance: Guaranteed Loans

Assistance Considerations:

- Maximum mortgage amount may not exceed 90% of estimated replacement cost
- State certification as to need for facility
- Loan maturity up to 25 years

Deadlines: Not Applicable

Range of Assistance Awarded: Not Available

HUD Decision Time: Processing time depends on the sponsors preparation

Information Contact:
Washington, D.C. Telephone: (202) 755–9280

Program: Mortgage Insurance – Nursing Homes and Intermediate Care Facilities

Eligibility: Investors, builders, developers, and private nonprofit corporations or associations licensed or regulated by the state

Purpose: To assist in financing the construction or rehabilitation of nursing homes and intermediate care facilities

Type of Assistance: Guaranteed Loans

Assistance Considerations:

- Guarantee limited to 90% of value of physical improvement.
- Current maximum interest rate is 9 ½% plus ½%.
- Loan maturity is up to 40 years.

Deadlines for Application: Established on a case–by–case basis.

Range of Assistance Awarded: Not Available

HUD Decision Time: Dependent on sponsor's application preparation

Information Contact:
Washington, D.C. Telephone: (202) 755–9280

U.S Department of Housing and Urban Development

Program: Indian Community Development

Eligibility: *Indian Tribes otherwise eligible for assistance under the Indian Self-Determination and Education Assistance Act or under the State and Local Assistance Act*

Purpose: To assist Indian Tribes and Alaska Natives in the development of viable communities and expand economic opportunities

Type of Assistance: Project Grants. No formula and matching requirements.

Assistance Considerations:

- Projects must principally aid persons of low and moderate income.

Deadlines for Application Submission:
HUD established deadlines are published in the Federal Register.

Range of Assistance Awarded: $43,000 to $1,714,532

HUD Decision Time: Target time is 45 days for pre-applications and 45 days for full applications.

Information Contact:
Washington, D.C. Telephone: (202) 755–6092

Program: Urban Development Action Grants

Eligibility: Distressed cities and urban counties which meet criteria specified in regulations (24 CFR Part 570.452)

Purpose: To alleviate physical and economic deterioration through economic development and neighborhood revitalization

Type of Assistance: Project Grants

Assistance Considerations:

- More favorable consideration given to projects that include funds from the state or other public entities.
- Assistance is provided for a project that can be completed in about 4 years.

Deadlines for Application Submission:
Metropolitan cities and urban counties in January, April, July and October. Small cities in February, May, August and November.

Range of Assistance Awarded:

Metro cities	$85,000 to $13,500,000
Small cities	$77,700 to $5,700,000

HUD Decision Time: Within 60 to 90 days

Information Contact:
Washington, D.C. *Telephone:* (202) 472–3947

U.S. Department of the Interior

Bureau of Indian Affairs

Program: Indian Loans – Economic Development

Eligibility: Indians, Alaska Natives, Tribes, and Indian Organizations

Purpose: *To promote the economic development of a Federal Indian Reservation*

Types of Assistance: Project Grants; Direct Loans; Guaranteed Loans

Assistance Considerations:

- Funds must be unavailable from other *sources under reasonable terms and conditions.*
- Individual applicants must be a member of a federally recognized tribe and not members of an Indian organization that conducts its own credit program.
- Funds must be used on or near a Federal Indian Reservation.

Deadlines for Application Submission: None

Range of Assistance Awarded: $100 to over $1,000,000

Maximum Assistance Authorized:
Guarantees limited to 90% of the loan; Grants limited to 40% or $50,000 of the projects cost.

DOI Decision Time: 60 days depending upon completeness of loan application.

Information Contact:
Washington, D.C. Telephone: (202) 343–5875

Small Business Administration

Program: Small Business Loans

Eligibility: *Any small business which is independently owned and operated, and is not dominant in its field*

Purpose: To assist small businesses, including agricultural enterprises, in obtaining credit

Type of Assistance: Direct Loans; Guaranteed Loans

Assistance Considerations:

- Funds must be unavailable from commercial sources under reasonable terms and conditions.
- *Funds cannot be used to pay off an unsecured creditor who is in a position to sustain loss.*
- *Applicant must meet SBA size standard for small business.*

Deadlines for Application Submission: None

Range of Assistance Awarded:
Guaranteed Loans $1,800 to $500,000;
Direct Loans $1,000 to $350,000.

SBA Decision Time: Within 3 to 60 days after application acceptance.

Information Contact:
Washington, D.C. Telephone: (202) 653–6570

Is More Information Available?

More detailed information on each program is available from the agency's office in Washington, D.C. You can get information on agency regulations, filing procedures and forms, and other general instructions. Agency personnel can also provide advice on eligibility and discuss matters specific to your geothermal project and its financing.

Unsolicited Proposals

In order to meet its energy objectives, DOE encourages any organization or individual to submit imaginative and innovative research or investigation proposals that will assist in the development of energy resources. When you initiate a proposal that is not in response to a formal DOE request, the proposal is considered to be unsolicited. DOE may accept and fund geothermal energy unsolicited proposals to carry out research, development and commercial demonstrations. In evaluating an unsolicited proposal, DOE considers whether it will duplicate work underway or contemplated by DOE, or whether the work proposed has been previously determined to have no merit or value, and whether funds are available to carry out such work. You are urged to informally consult with DOE, prior to preparing a written unsolicited proposal, to determine DOE's interest in your planned work. Funding for unsolicited proposals is highly competitive and prospective proposers have found informal discussions with DOE geothermal staff to be of value in reducing paperwork and minimizing lost time. DOE geothermal staff are available for consultation by contacting:

Division of Geothermal Energy,
RA–231
Office of the Assistant Secretary for
Resource Applications
U.S. Department of Energy
Washington, D.C. 20461
(202) 633–8760

ESC

SUBJ
GTHM
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STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER RIGHTS

DEE C. HANSEN
STATE ENGINEER

EARL M. STAKER
DEPUTY

200 EMPIRE BUILDING
231 EAST 400 SOUTH
SALT LAKE CITY, UTAH 84111
(801) 533-6071

DIRECTING ENGINEERS
HAROLD D. DONALDSON
DONALD C. NORSETH
STANLEY GREEN
ROBERT L. MORGAN

October 18, 1979

RECEIVED
OCT 22
ENERGY & TECHNOLOGY
DIVISION

John L. Griffith
U. S. Department of Energy
550 Second Street
Idaho Falls, Idaho 83401

Dear John:

This is the list of federal lease priorities for Utah. The formulation of the list was a joint effort between Peter Murphy of the UGMS, Duncan Foley and Debra Struhsacker of UURI, and myself.

I might mention that the assignment is still slightly confusing. In Utah, most of the federal lands which are close to the best prospective resource areas are already leased; in addition, many of the best current direct use prospects are located away from federal lands (e.g., the resource areas along the Wasatch Front). That means that the resource areas which have not yet been leased tend to be those areas where resource quality and user interest are generally lower.

Our primary criteria for the priority listing was that the area be a good prospect for early development, both in terms of resource quality and user interest, and, secondarily, that there be unleased federal lands near the resource area.

An alternative to this approach would have been to use federal land availability as the overriding criteria for prioritizing. This would have elevated the priority of sites which rank lower in terms of resource quality and current user interest, since they will certainly be developed someday even if development will not be feasible for several years.

The reason I mention this is that we considered the priority of the resource areas as if it applied only within the state of Utah. If the priority rankings from the different states are put in competition against each other, particularly in the allocation of funds and manpower for the leasing process, then we may have placed Utah at a disadvantage relative to states which took the other approach. Again, this is not a concern unless the priority rankings are used to shift funds or manpower to the significant benefit of some states and the corresponding detriment of others, and unless there is a significant conflict in the ranking criteria used by the various states.

If you have any questions about the resource areas we have listed, the priority rankings, or the question about the use of the lists, please call.

Yours very truly,

Ward Wagstaff

Ward Wagstaff

SUMMARY LISTING

Utah BLM Lands

	Resource Area	Potential Applications
1.	Roosevelt Hot Springs Beaver County	Electrical power generation, industrial, agricultural

A 20 MWe R&D plant is planned for the early 1980's, followed by larger plants a few years later. Total resource capacity is estimated to be about 300 MWe.

2.	Monroe/Joseph Sevier County	District heating, greenhouses, commercial, crop processing, light industry

A district heating project is currently in progress. The potential exists for additional direct use projects in the area, in addition to the expansion of the planned project.

3.	Newcastle area Iron County	Greenhouses, agricultural, light industry

A greenhousing project has recently begun operation near Newcastle, and plans include expansion. The resource apparently is about 88^{o} C, has low TDS, and has good flow rates.

4.	Beryl/Escalante Desert Iron County	Agricultural complex, greenhouses, crop processing, industrial, aquaculture. Possible eventual binary power production

A large agricultural complex is being considered. Resources are reported to be about 149^{o} C and low TDS.

Utah BLM Lands (Continued)

	Resource Area	Potential Applications
5.	Cove Fort Millard and Beaver Counties	Electric Power, greenhouses, crop processing, industrial, aquaculture. Possible eventual binary power production

Electrical exploration so far has been unsuccessful at Cove Fort; however, direct uses such as greenhouses or light industry may be able to take advantage of the exploratory work already done, particularly deep wells. Power generation using binary systems may eventually be feasible.

6.	Thermo Hot Springs Area Beaver and Iron Counties	Power generation, agriculture, aquaculture, greenhousing, light industry

Thermo appears to be a possible electrical power production site, particularly if binary technology becomes feasible. The resource temperature is reported to be in the 175-205° C range; alternative uses might include agricultural, aquaculture, greenhousing, or light industry.

7.	Abraham Hot Springs Area Juab County	Light industry, greenhousing, agricultural, mining uses

Abraham Hot Springs issue at temperatures up to 82° C. The springs area is somewhat isolated, but the development potential appears good.

SUMMARY LISTING

Utah USFS Lands

Resource Area	Potential Applications
1. Monroe/Joseph Sevier County	District heating, greenhouses, commercial, crop processing, light industry

A district heating project is currently in progress. The potential exists for additional direct use projects in the area, in addition to the expansion of the planned project.

2. Newcastle area Iron County	Greenhouses, agricultural, light industry

A greenhousing project has recently begun operation near Newcastle, and plans include expansion. The resource apparently is about 88° C, has low TDS, and has good flow rates.

3. Cove Fort area Millard and Beaver Counties	Electrical power, greenhouses, crop processing, industrial, aquaculture. Possible eventual binary power production

Electrical exploration so far has been unsuccessful at Cove Fort; however, direct users such as greenhouses or light industry may be able to take advantage of the exploratory work already done, particularly deep wells. Power generation using binary systems may eventually be feasible.

Resource Area: Roosevelt Hot Springs, Beaver County, Townships 26 and 27 South, Range 9 West, and surrounding area. Deep well temperatures up to 260° C have been measured. Resource capacity is generally estimated to be about 300 MWe.

Use Potential: Deep drilling has confirmed the presence of a commercial reservoir. Current development plans include a 20 MWe R&D power plant in the early 1980's, followed by full sized (55 MWe) plants a few years later. Most of the land within and close to the unit boundaries have been leased; however, the drilling by McCulloch of a deep well several miles west of the main prospect area may spark interest in leasing peripheral lands. Alternate uses might include agricultural uses, crop processing, greenhouses, or light industry. At this time, no plans for secondary uses of the geothermal fluid in conjunction with power generation have been made.

Policy Issues: Beaver County has expressed interest in operating a power utility, and a feasibility study was conducted by a consulting firm to assess the viability of a county-operated power system. The feasibility study considered the geothermal resource at Roosevelt as a possible source for the power. The area is somewhat depressed economically, and new industry would be welcome, particularly if it created employment opportunities within the county. A major consideration for development will be the availability of water; groundwater in the Milford area is being depleted and disposal restrictions such as reinjection will probably be imposed.

Resource Area: Monroe/Joseph area, Sevier County, Townships 24 and 25 South, Range 3 West, and Township 25 South, Range 4 West. Well temperatures of about 83° C have been measured in a production well for Monroe City. Geothermometry suggests temperatures up to about 101° C.

Use Potential: Monroe is a rural community which is growing quite rapidly. Industries in the area include agriculture, with extensive mining occuring throughout the county. A resort is currently operating at Monroe, and a district heating project for Monroe city, utilizing cost share funds from DOE, is in the initial stages of development. Potential uses include space heating and greenhouses, both of which are part of the expansion plans of the city project, and light industry such as crop processing or distillation.

Policy Issues: Monroe is in an area of restricted groundwater use, so injection or other methods of compensation will be required. Both BLM and USFS have lands in close proximity to the springs, the town, and the geothermal project; both should be prepared not only for geothermal lease applications on those lands, but also for requests for rights-of-way, special use permits, etc., which may be associated with geothermal projects.

Resource Area: Newcastle, Iron County, Township 36 South, Ranges 15 and 16 South. Two shallow wells have been drilled which reportedly produce up to 1000 gpm of 96° C water with low TDS.

Use Potential: Newcastle is predominantly an agricultural area, with mining at some locations. Two greenhouses have recently begun operation, and the operation is expected to expand. The area is close to a major highway and a railway runs within 20 miles of the resource area. Potential uses include greenhouses, agricultural complexes, or other light industry.

Policy Issues: The Newcastle area is one of restricted ground water withdrawal, so that reinjection or other compensating measures will be required. Economic development in the area would be welcome.

Resource Area: Beryl/Escalante Desert, Iron County, Townships 33 and 34 South, Ranges 16 and 17 West. Water from a deep exploratory well is reported to be about 149° with less than 4000 ppm dissolved solids.

Use Potential: The predominant industry in the area is agriculture; some mining occurs in the surrounding mountains. A railway and several major highways run through the area. McCulloch is considering a large agricultural complex which would utilize heat from an existing geothermal well; other potential uses might include greenhouses, crop processing, light industry, aquaculture, etc.. Moderate temperature electrical production may be an eventual possibility.

Policy Issues: The area is one of restricted groundwater use, so reinjection or other compensating measures would be required. New economic development in the area would be welcome. The area does not appear to be environmentally sensitive.

Resource Area: Cove Fort and surrounding area, Beaver and Millard Counties, Townships 24, 25, and 26 South, Ranges 6 and 7 West. Deep drilling in the area has been difficult and a resource suitable for electrical power generation has not been located; however, hot water was located at depth, and some of the existing deep wells may be able to provide water for direct uses.

Use Potential: Although electrical exploration at Cove Fort has not been fruitful, further exploration should not be ruled out. Also, some of the deep exploratory wells may be used for direct uses such as greenhouses, agriculture, or light industry. The area is not far from agricultural areas, and mining (sulphur) is conducted in the prospect area.

Policy Issues: Both state and local governments would welcome economic growth in the area. Groundwater availability may be an issue, depending on the location. The prospect covers BLM, USFS, State, and private lands.

Resource Area:	Thermo Hot Springs, Beaver and Iron Counties, Townships 30 and 31 South, Ranges 12 and 13 West. One deep well has been drilled, and temperatures are reported to be in the range of 175-205° C, with good quality water and natural flow rates. Extensive temperature gradient and geophysical studies have been conducted in the area.
Use Potential:	The Thermo geothermal prospect is located about 20 to 30 miles southwest of Milford. It is not far from extensive agricultural areas, and mining operations are scattered through Beaver and Iron Counties. The resource temperatures indicate that it might be suitable for a binary power generation system when the proper technology becomes available. Alternative uses might include agriculture, aquaculture, greenhouses, or light industry. The area is close to railroad lines but is some distance from a major highway.
Policy Issues:	The area around Thermo is to some degree depressed economically, and new industry would be welcome. Groundwater withdrawal in the area is restricted, so reinjection will probably be required. The area does not appear to be environmentally sensitive.

Resource Area: Abraham (Crater, Baker) Hot Springs, Juab County, Township 14 South, Range 8 West, and surrounding areas. Spring temperatures range up to 82° C. Some exploratory work has been done in the prospect area, including temperature gradient surveys.

Use Potential: Abraham Hot Springs is somewhat isolated, but a highway does run within a few miles of the spring area. Development in the area would be welcome, and a substantial amount of energy-related development is expected to occur in Juab County. The resource would probably be suitable for uses such as greenhouses, light industry, agricultural complexes, or mining uses.

Policy Issues: Some water from the hot springs is involved in litigation over water rights; this may or may not affect development. Juab County is expected to experience significant growth due to energy-related projects such as the IPP project.

1980 Jackling Lecture

Herbert E. Hawkes

"For his pioneering leadership in the science and technology of mineral exploration, especially in the development and world-wide application of geochemical methods as major exploration tools, and for his lecture 'Geothermal Hydrogen'."

Geothermal Hydrogen

Hydrogen gas is not an abundant component of the environment in which we live and breathe. Atmospheric air contains only about half a part per million of elemental hydrogen, as compared with 21%, or 210,000 ppm, of oxygen. We need oxygen to support life. Free hydrogen, on the other hand, is thought of as hardly more than a curiosity in the natural environment. It is easy to forget that in a chemical system dominated by water, elemental hydrogen represents one of the two end members of the oxidation-reduction spectrum. It is, in fact, a prime mover in the energy balance between the oxygen-rich surface of the earth, and the oxygen-deficient deep-seated environment.

Perhaps because of our fascination with oxygen as a means of supporting life, hydrogen as such has been short-changed in the geochemical literature. This is regrettable, as molecular hydrogen has both physical and chemical properties that are strikingly different from any other member of the periodic table, or for that matter of any other naturally occurring substance. Since it is a somewhat novel subject, it is perhaps not entirely inappropriate that some aspects of the geochemistry of free hydrogen might be discussed in the lecture honoring Daniel C. Jackling, a pioneer in novel approaches to man's problems. In this lecture, particular reference will be made to possible chemical reactions between molecular hydrogen and organic matter in the sedimentary column.

Hydrogenation of Petroleum

Petroleum consists primarily of an extremely complex mixture of hydrocarbons, or compounds of hydrogen with carbon. Most hydrocarbons fall into three generic groups: (1) the aromatics, containing one or more C_6H_6 benzene rings; (2) the naphthenes, containing ring-structured groups with the formula C_nH_{2n}; and (3) the paraffins, with open-chain molecules with the general formula C_nH_{2n+2}. The atomic ratio of hydrogen to carbon ranges from one-to-one or less in the aromatics to four-to-one in methane, CH_4, which is the light end member of the paraffin series. The over-all hydrogen-carbon ratio of a sample of petroleum is simply a reflection of the relative proportions of these different hydrocarbons.

A strong positive correlation has been noted between the H:C ratio in a cruide oil, and both its age and depth of buriel below the present surface. An example of this relationship is shown in Fig. 1. The older the crude and the deeper the reservoir, the higher the hydrogen-carbon ratio. This

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H. E. Hawkes, Member SME, is a consultant, Tucson, AZ. Lecture presented at the AIME Annual Meeting, Las Vegas, NV, Feb. 1980.

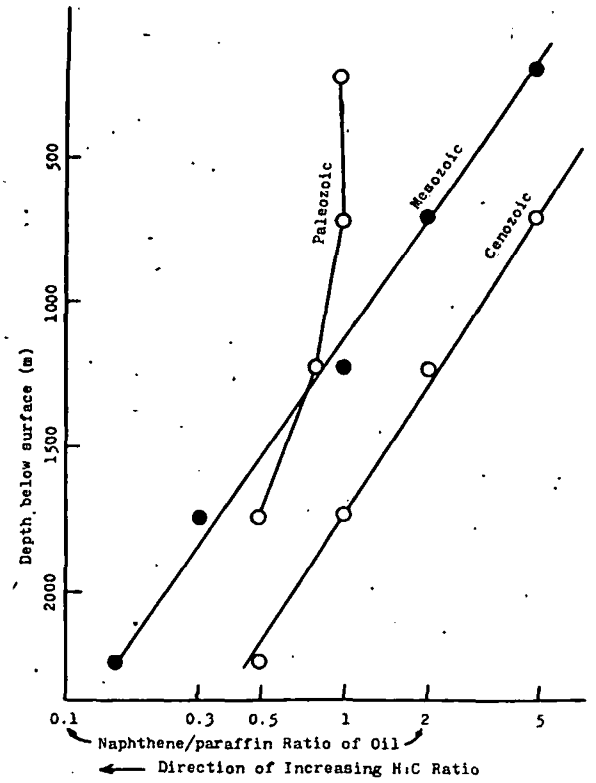

Fig. 1—Relation of hydrogen-carbon ratio in 67 Russian crude oils to age and depth of burial (Hunt, 1979).

relationship implies a progressive change of composition of the crude oil as it ages, or "matures." It raises an intriguing question as to whether the maturing of petroleum takes place in a closed or in an open system.

If it is in a closed system, it would be necessary to postulate a separation of the organic matter contained in a sedimentary rock into two phases, one an immobile fraction characterized by a decreasing H:C ratio, and the other a fluid phase consisting of liquid petroleum with a progressively increasing H:C ratio. This is, in fact, the mechanism that is generally accepted by petroleum geochemists, a mechanism that goes by the name "disproportionation." A low-hydrogen, tar-like residue of aromatic hydrocarbons, or "pyrobitumen," remains in the source rock, while a high-hydrogen fraction enters the porous rocks of the reservoir in a form that can be extracted by drilling and pumping.

The other possibility is that we have an open system, and that part or all of the hydrogen needed for the progressive increase in the H:C ratio comes from outside the system. If we are to accept this possibility, we are faced with another problem, that of a source for the hydrogen needed for this hydrogenation process. Some 40 years ago, Wallace Pratt (1934) recognized this dilemma, and postulated a reaction between liquid petroleum and methane, or "methylation," to produce a progressively higher H:C ratio with time and depth. He was still left with an unaswered question of the ultimate source of the hydrogen-rich methane needed for this reaction.

Hydrogen Equilibria in Subsurface Rocks

Now in another branch of earth science, that having to do with chemical equilibria at high temperatures and pressures, laboratory experiments have shown that water in the presence of minerals containing ferrous iron tends to break down to yield free hydrogen. An example is the following reaction involving quartz, fayalite and magnetite in contact with water:

$$\underset{\text{Fayalite}}{3Fe_2SiO_4} + \underset{\text{water}}{2H_2O} = \underset{\text{magnetite}}{2Fe_3O_4} + \underset{\text{quartz}}{3SiO_2} + \underset{\text{hydrogen}}{2H_2}$$

When these reactants are at equilibrium, the molecular ratio of elemental hydrogen to water is in the order of 1 to 30 (Eugster and Skippen, 1967). Any other silicate mineral containing ferrous iron would behave in a similar way to give a hydrogen-water ratio in more or less the same range.

The speed of the reaction whereby water dissociates into hydrogen depends on the temperature. At temperatures near the surface of the earth, reactions like this take place so slowly that they can be disregarded. However, if temperatures are raised to about 300° C (or just under 600° F) the reaction proceeds much more rapidly, so that the 1-to-30 ratio of hydrogen to water is quickly established. Temperatures in this range and above are reached at depths of 10 to 15 km, as shown in Fig. 2.

All the evidence points to an abundance of water at these depths. According to accepted estimates, average igneous rocks contain 0.6% water by weight. To be ultraconservative, we might assume an equilibrium ratio of hydrogen to water of 1 in 100 instead of 1 in 30. Then such a rock should still contain at least 7 ppm of free hydrogen, again by weight. If this rock were brought to the surface and the hydrogen extracted, it would yield about 75 cm^3 of hydrogen gas per kg of rock (Fig. 3).

If 100 cm^3 of the water in equilibrium with this rock were brought to the surface and the hydrogen extracted, it would yield about 1200 cm^3 of hydrogen gas (Fig. 4). Now water saturated with hydrogen at atmospheric pressure can only hold about 2 cm^3 of hydrogen per 100 cm^3 of water. Thus, if water did migrate upwards from depths, hydrogen gas would be continually coming out of solution as bubbles.

Atmospheric air contains about half a ppm hydrogen by volume. Normal water at the surface of the earth in contact with this air would contain on the order of a millionth of a cm^3 per 100 cm^3 of water. Thus, the contrast in the ratio of hydrogen to water between a depth of 15 km and the surface is about a billion (10^9) to one.

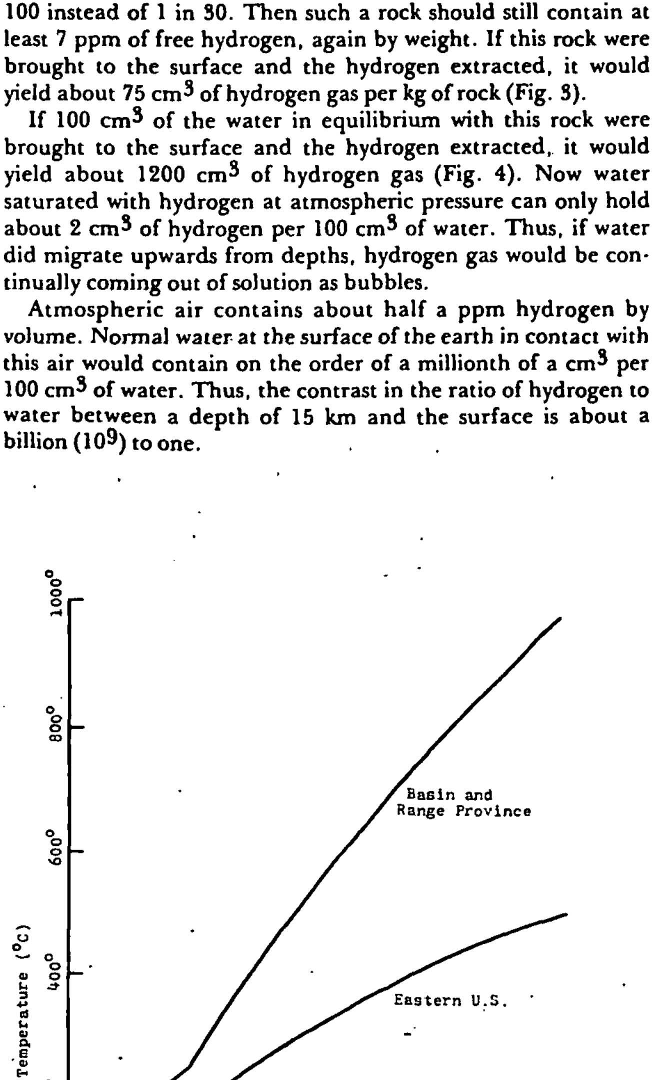

Fig. 2—Temperature variation with depth in contrasting regions (Press and Siever, 1974).

In addition to water, there is also abundant evidence that carbon in various forms (carbonates, carbon dioxide and monoxide) is fairly abundant in the depths of the earth. If carbon compounds are added to the system containing water and ferrous minerals, methane (CH_4) and possibly other hydrocarbons may join hydrogen as members of the equilibrium assemblage.

The hydrogen-methane environment that prevails at depths of 15 km within the earth is in dramatic contrast with the oxygen environment of the earth's surface. It represents what for practical purposes is an unlimited source of energy in our energy-starved society, if some means could be developed for somehow bringing the hydrogen and oxygen together where they could react. It is encouraging to see that serious proposals have already been made for research and development of this potential source of energy (Gold, 1979).

If free hydrogen actually does occur in substantial concentrations at the very moderate depths of 15 km, could this effectively unlimited source be what is needed for the maturing of petroleum? Is it possible that molecular hydrogen might be steadily percolating upwards by a process of diffusion over short distances, combined with flow through cracks and fissures over longer distances, as suggested diagrammatically in Fig. 5? And could this steady upward flow be feeding the immature petroleum with what it needs to increase its H:C ratio? Although temperatures and pressures in most oil reservoirs might be below those needed for spontaneous attainment of equilibrium, anerobic bacteria might be serving as catalysts in the hydrogenation process. Bacteria are, in fact, known that thrive in an atmosphere of hydrogen, and that derive their vital energy from the hydrogenation of organic matter (Shea, 1968; Zajic, 1969).

Migration of Hydrogen from Depth

The idea of deep-seated hydrogen as an agent in the maturing of petroleum was suggested eight years ago in a short paper in the petroleum literature (Hawkes, 1972). It did not receive much attention at that time, as very little was known then of the effective permeability of crystalline rocks. In other words, it was difficult to conceive a mechanism whereby gases like hydrogen or methane could actually migrate upwards through many kilometers of massive, crystalline rocks. Since that time, however, a considerable body of information about the movement of fluids in this zone has come out of research on geothermal energy. Geothermal fluids, like hydrogen, have to get out somehow. The question is, how? Basically, there are just three mechanisms whereby gases and other fluids can migrate through a crystalline rock.

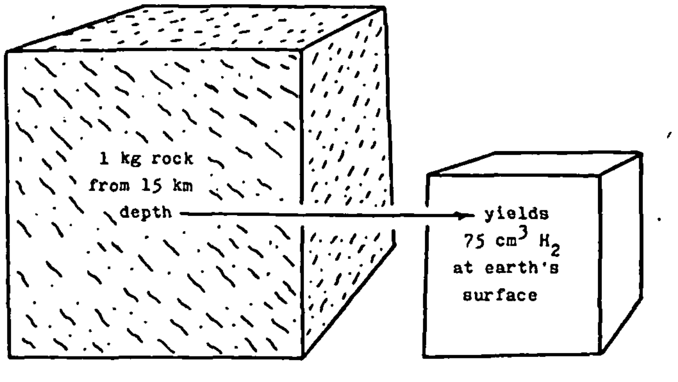

Fig. 3—Hydrogen gas contained in deep-seated rocks.

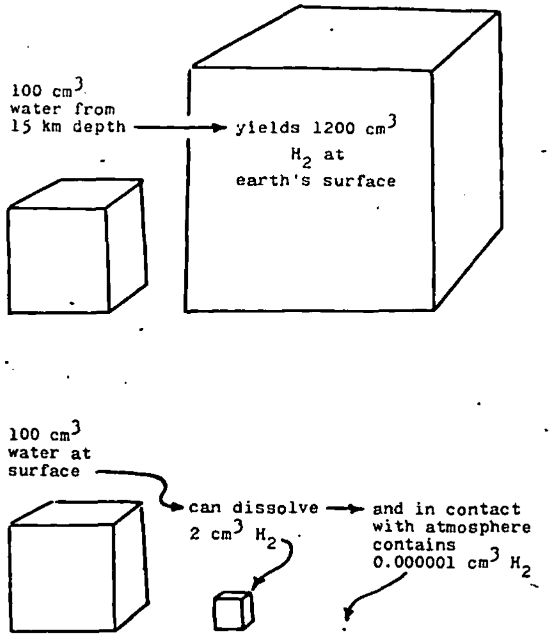

Fig. 4—Hydrogen gas contained in water from 15 km depth and at surface.

The first of these is diffusion through crystal lattices and water-filled pore spaces. Hydrogen molecules have the smallest diameter and the greatest speed of movement at a given temperature of any component of the system. These properties both favor differential movement by diffusion. It is known from laboratory experiments at elevated temperatures that hydrogen diffuses very rapidly through both metals and glass. In fact, metallic palladium is used in pressure-bomb experiments as a kind of sieve that permits hydrogen to pass through almost as if it weren't there, but that stands as a barrier to all the other gases taking part in the reaction. Little or no experimental work has been published on the diffusion of hydrogen through silicate

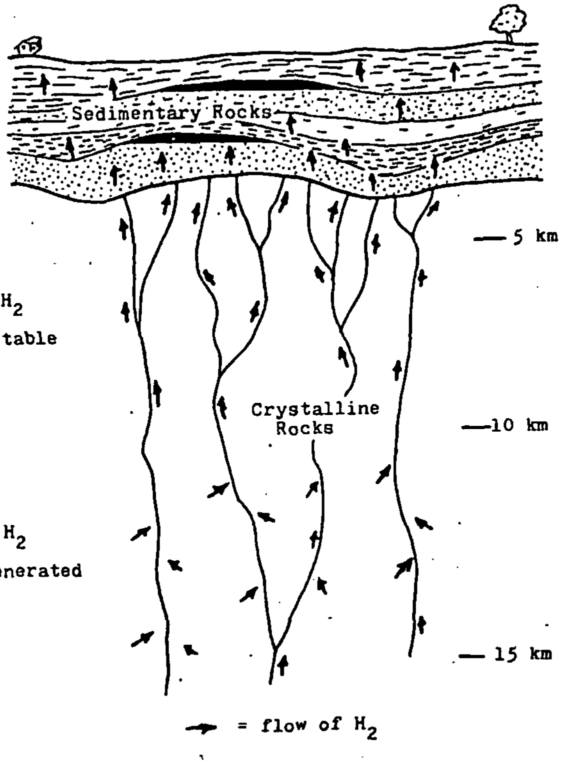

Fig. 5—Diagram showing hypothetical flow of hydrogen near earth's surface.

lattices, although a diffusion rate similar to that through glass would seem likely. If so, diffusion should be enough to equalize any gross variations in the concentration of hydrogen over a scale of centimeters and a time span of only a few years.

The second mechanism for the migration of material at depth is fluid flow through microcracks. Diffusion is probably of minor importance here. Microcracks consist of open channels ranging down to 0.1 or even 0.03 microns in width (Richter and Simmons, 1976). If a microcrack is to serve as a conduit for the escape of fluids, it must of course have some continuity. The continuity of a system of microcracks, and hence the overall permeability of the rock, can be estimated by various geophysical methods. These studies have shown that rock permeabilities in excess of 10^{-14} cm^2 extend to depths of at least 15 km (Norton, 1976; Norton and Knapp, 1977). It is noteworthy that this is also the depth at which chemical equilibria are approached. A permeability of 10^{-14} cm^2 is enough to permit substantial mass movement of the fluids contained in the cracks, provided an adequate driving force is applied. Such a force can come, for example, from the density contrasts that are generated thermally by an igneous intrusion. It has been calculated that under the most favorable conditions directly over a hot pluton, and assuming 10^{-14} cm^2 permeability, the fluid in the microcracks can flow at a rate of 10^{-3} g/m^2s, or about 20 kg/m^2 per year (Norton and Knight, 1977). This is a very substantial flow rate.

Finally we have mass movement through open fissures and joints, and the relatively open pore spaces of clastic sedimentary rocks. The same driving forces that could push fluid through microcracks would of course be even more effective in a rock of high permeability. To these forces could be added the forces of non-thermal origin, such as pressure gradients of normal artesian waters, and the buoyancy effect of exsolving gas bubbles.

Observed Hydrogen in Subsurface Environments

Theoretical arguments for the existence of free hydrogen in subsurface rocks and for its migration upwards into the surface environment are in fact supported fairly consistently by actual observations. Gases extracted from igneous and metamorphic rocks are commonly found to contain easily measured concentrations of elemental hydrogen, as shown in Table 1. Gases sampled from deep fissures have also shown significant concentrations of hydrogen. For example, Kravtsov, et al. (1967) over a period of three years made measurements of gases emanating from cracks in the Khibiny alkaline complex, Kola Peninsula, USSR, where it was exposed in a deep railway tunnel. They found hydrogen varying from 2.8 to 3.8% with no general increase or diminution over the entire three-year period.

Second-hand evidence for free hydrogen in fissures comes from observations of occluded hydrogen trapped in hydrothermal minerals (Table 2). The conclusion here is almost inescapable, that substantial concentrations of molecular hydrogen were present in the hydrothermal fluids from which these ore minerals were deposited. The disparity in content between the various minerals may be due in part to time variations in the concentrations during the hydrothermal deposition, and in part to subsequent leakage.

Table 1—Occluded Hydrogen in Rocks* (in cm^3/kg)

Alkaline igneous rocks Kola, USSR	0.15 to 6.41
Archean gneisses Olinogorsk, USSR	1.97 to 3.91
Metamorphic rocks Kola, USSR	1.47 to 4.60

Source: Linde, I.F., 1964; Gorstka, Petersil'e, and Pripachkin, 1965; Petersil'e and Pripachkin, 1962, 1963.

As might be expected, hydrogen is present in major quantities in most volcanic gases, as well as in many of the gases dissolved in geothermal waters. Table 3 shows a comparision between the hydrogen actually measured in two typical volcanic gases, compared with what would be theoretically expected from a basalt containing both water and ferrous iron.

Hydrogen in Zone of Oxidation

Now when our hypothetical flux of hydrogen reaches the zone of oxidation, it would get embroiled in many new kinds of biological and chemical reactions. In the oxidation zone, bacteria together with some higher life forms can under appropriate conditions both generate and consume free hydrogen. Furthermore, solar radiation acting on the constituents of the atmosphere can also both generate and consume hydrogen. These factors are responsible for the so-called "sources" and "sinks" of hydrogen at and near the surface that are the concern of environmental chemists.

One of the most active hydrogen sinks is found in normal soil. Laboratory studies using samples of various soils in their natural state, without sterilization, in an atmosphere containing the same amount of hydrogen as ordinary air, show a logarithmic decay of hydrogen to negligible concentrations over a period of an hour or so (Seiler, 1978). These studies were carried out by environmental chemists, interested in the chemistry of the atmosphere. However, the conclusions are equally pertinent for hydrogen reaching the soil from below. The implications are that in soil covered areas, a substantial fraction of any free hydrogen emanating from depth would be destroyed by bacteria before it reached the atmosphere. For areas not covered by soil, and in cold weather when the bacteria were dormant, the hydrogen might safely reach the open air.

In the oceans, the common reaction involving hydrogen is its generation by biological activity in the sunlit zones near the surface (Seiler, 1978). Concentrations here are about three times what would be in equilibrium with the hydrogen in the air. In fact, the hydrogen content of air sampled directly over the surface of the water is measurably higher than the average for normal air. Thus, the ocean is effectively serving as a source of hydrogen in the atmospheric hydrogen budget.

Coming now to what happens in the free atmosphere, we run into an extremely complicated series of reactions. Except for water vapor, the major constituents of air are nitrogen, oxygen, argon, and carbon dioxide. Minor constituents include the other noble gases, which are unreactive, and a long list of molecular species that result from photochemical reactions, or "photolysis." Free hydrogen is one of these. It is generated principally by a series of photochemical reactions starting with

Table 2—Occluded Gases in Hydrothermal Minerals* (in cm^3/kg)

	H_2	CO_2	CH_4
Garnet	36.0	60.0	3.0
Sphalerite I	5.6	1.9	1.6
Calcite	1.9	7.7	0.5
Quartz	102.0	4.4	24.0
Sphalerite II	15.0	1.0	3.0
Galena	2.6	1.6	—
Barite	6.8	9.1	6.0

Source: Kurusai mining district, USSR, Elinson and Sazonov, 1966, Chem. Abst.

Table 3—Hydrogen in Volcanic Gases* (in volume-percent)

	Average Hawaiian	Ert'Ale, Ethiopia	Predicted
H_2O	79.31	79.4	79.0
H_2	0.58	1.49	between 0.75 and 1.88

**Source: Holland, 1978, Wiley-Interscience, p. 289.*

Table 4—World Hydrogen Budget* (in units of 10^{13} g/yr)

Sources		Sinks	
Cultural	2	Uptake by soil	12
Methane	2	Photolytic oxidation	1
Oceans	0.4		
Volcanic	0.02		
Deficiency	*8.58*		
	13		13

**Source: Seiler, 1978, Environmental Biogeochemistry and Geomicrobiology," p. 807.*

methane, which in turn comes in part from bacterial decomposition of organic matter and in part from industrial activity. Free hydrogen is consumed in the atmosphere by reaction with the OH radical, which in turn is generated photolytically from water and oxygen.

Apparently there is no mass movement of elemental hydrogen as such from the lower atmosphere into the stratosphere. The hydrogen that emanates into outer space from the upper atmosphere is supplied by the dissociation of local water vapor.

From all this we may write up a budget for free hydrogen in the atmosphere, based on the best estimates for the various raction rates (Table 4). This shows that the sources and sinks are not balanced—more hydrogen is being consumed in the sinks than is being generated in the sources. If these estimates are correct, this must mean one of two things: Either the concentration of hydrogen in the atmosphere is steadily decreasing (for which there is no evidence), or there is another source that has not been identified, such as perhaps the depths of the earth.

Conclusions

In summary, thermodynamic studies show that what is effectively an unlimited source of free hydrogen, together with the gases that are compatible with it such as methane, exists at depths of 15 km and more below the surface. Recent research suggests that adequate channelways and driving forces are present to bring this hydrogen up through the crystalline basement into the sedimentary section and the environment of petroleum accumulation. Although hydrogenation of petroleum within the reservoirs has not been demonstrated, bacteria are known that derive their vital energy from the hydrogenation of organic matter. Various lines of evidence, including the observation of elemental hydrogen in igneous rocks, the composition of volcanic and geothermal gases, and the minerals of hydrothermal vein deposits, are all compatible with the concept of the upward migration of hydrogen from depth. And finally, study of the sources and sinks of hydrogen in the atmosphere shows a deficiency that could at least theoretically be accounted for by a source at depth.

Thus, although the disproportionation mechanism accepted by petroleum geochemists may account for a part of the observed increase in the hydrogen-carbon ratio of crude oil with age and depth of burial, a part also may be provided by the upward migration of hydrogen from a geothermal source.

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Geophysical Investigations in the Self-sealing Geothermal Fields *

1968

Bulletin Volcanologique
V. 31

G. FACCA
Interregional Technical Adviser, U. N., N. Y.

All geothermal fields producing commercial steam have a cap-rock above the main producing aquifer.

Two types of cap-rock are known: in the first type, the impermeability is original; in the second, the impermeability is originated by the hydrothermal activity itself. The fields pertaining to the second type are called the « self-sealing » fields.

The basic processes of the self-sealing are the rock-alteration, in the first place kaolinization, and the filling of the voids by deposition of different minerals, most commonly silica and calcite.

The Author had recently the possibility of studying a geothermal area, Ahuachapan in El Salvador, C. A., where strong evidence of the self-sealing process is offered. In the area, geochemical, gravimetric, electrical resistivity, magnetometric and gradient surveys have been carried out under the supervision of Mr. KAPPELMEYR.

The interpretation of the field data indicates that it is possible to gather valuable information on the extent and location of self-sealing by the means of appropriate geophysical surveys.

Should this be confirmed by further investigations, the geothermal exploration for commercial hot fluids shall be carried out more effectively and at a lower cost.

The geothermal exploration of the Ahuachapan area began in the year 1953, when DURR started a series of geological, geochemical and geophysical investigations; his highly valuable work continued till 1961.

In 1966, the United Nations Special Fund approved a geothermal

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* Paper presented at the Heat Flow Symposium, Zürich, Sept. 1967, and accepted for publication by the organizing commitee.

project in El Salvador and a new series of systematic investigations are currently carried out by the Project Manager, Mr. FALLEN BAILEY.

During the last spring, Mr. PALMASSON, Mr. SMITH and the Author visited the country as technical advisers of the United Nations and we where allowed to study all the available information.

In the Ahuachapan area, hot springs, mud volcanoes, steam vents and other manifestations of abnormal heat are common. In a previous geochemical study by Mr. F. TONANI, the self-sealing process has been recognized. Several manifestations in the eastern portion of the geothermal area have been classified as leakage manifestations. In the same area, several shallow wells show severe hydrothermal clay alteration and impervious rocks. On the contrary, the western El Salitre and allied hot springs are not leakage manifestations, the shallow wells indicate poor rock alteration, the thermal gradients point to convection and hence permeability.

Several electrical resistivity « lows » were surveyed in both areas. In the eastern area the resistivity « lows » are linked with low magnetic values, whereas in the western area the resistivity lows are linked with magnetic « highs ». A simple explanation of those facts emerged during a discussion with Mr. PALMASSON. The high magnetic values in volcanic rocks are mainly due to the magnetite; this mineral can be altered to pyrite by the geothermal fluids and hence the magnetism of the country rock decreases.

On the other side, a resistivity low can be due either to severe rock altration or to saline hot or cold ground water. An increase in temperature increases the electrical conductivity in any thermal area. It seems clear that the resistivity lows of the western highly magnetic area are due to the convective hot waters, whereas in the eastern poorly magnetic area the resistivity lows are due to the change in the rock (as induced by alteration), in spite of low salinity.

As a consequence, the commercial geothermal possibilities of the eastern area appear to be much better than those of the western area.

Mr. J. B. KOENIG, geologist of the California Division of Mines, is carrying out similar geothermal investigations in Coso Springs area in the Basin-and-Range California geomorphyc province. During an informal discussion on the Ahuachapan interpretation as given above, Mr. Koenig related similar findings in the Coso Hot Springs area. In a written personal communication, referring to the Coso Hot Springs area he states as follows: « Detailed magnetic traverses have resulted in the recognition of 'magnetic signatures' of the major rock types

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in the area, and in the probable recognition of their hydrothermally-altered equivalents. Hydrothermal alteration is expressed as magnetic lows, due to destruction and removal of magnetite from the rocks by heated fluids. In some areas, in a linear zone to the west and especially the south of Coso Hot Springs, magnetic lows in areas of relatively fresh granite, are believed to be caused by concealed or buried hydrothermal alteration. That is, areas in which the heated fluids did not ascend to the present surface.

Geochemical traverses have determined mercury 'leakage' along the zones of heat alteration at the surface. Similar traverses will be necessary over the areas of 'blind' magnetic lows..

A test well drilled into the fault zone to a depth of 375 feet revealed intense hydrothermal alteration, and a shallow, probably perched water table. Alteration of granitic rocks has resulted in kaolinization of feldspar, and destruction of mafic minerals. Quartz, alone, remains unaffected ».

Electrical resistivity and gravimetric surveys have been planned for the area.

Three conclusions can be pointed out from the observations in the Ahuachapan and Coso geothermal areas:

1. - Rock alterations can be usefully investigated by resistivity and magnetic surveys and the two methods should be used concurrently.

2. - The self-sealed areas in volcanic rocks can be detected by those low-cost geophysical methods, once the self-sealing process has been demonstrated by the geochemical investigations.

3. - The geochemical investigations are needed in programming and interpreting the geophysical surveys. The geological and geochemical studies are the starting points of any geothermal exploration programme.

Manuscript received Nov. 1967

UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
SAN FRANCISCO OPERATIONS OFFICE
1333 BROADWAY
OAKLAND, CALIFORNIA 94612

SUBJ
GHTM
GLGP

May 27, 1977

Dear Geothermist:

In case you did not know it, we signed the first Geothermal Loan Guaranty on May 6, 1977. The guaranty was for a loan of $9.03 million by the Bank of America to the Republic-1975 Geothermal Energy Drilling Program. On Sunday, May 8, the first well drilled with funds made available through the GLGP was "spudded."

At the closing ceremony, which was presided over by Don Reardon, Acting Manager of SAN, and attended by Charles Fullerton, Vice President, Bank of America, and Robert Rex, President of Republic Geothermal, Inc., the Bank of America presented ERDA a check for $27,442.00 - the first year's user fee -- and a check of $2,250,000 to Republic-1975 -- the first disbursement in Milestone 1.

A copy of the news release is enclosed (for your information).

In approving this application, ERDA had to make the following Findings and Determinations:

1. Application complies with GLGP Regulations (10 CFR 790);
2. Project will not have a significant affect on the quality of the human environment;
3. The risks are acceptable;
4. Project is consistent with the goals and objectives of P.L. 93-410;
5. Overall probability of success is 63% or higher; and
6. There is a reasonable assurance that the loan will be paid off.

When Acting Administrator Robert Fri approved this application, several important principles were established, including:

1. ERDA will share both the financial and technological risks of developing this important resource with the lenders and borrowers;

2. ERDA will encourage, to the maximum extent practicable, participation by commercial lenders if the interest rates are reasonable (approximately 120%-125% of floating prime appears to be a maximum acceptable rate at this time).
3. ERDA will, on a case-by-case basis and where appropriate, allow equity participation on a 25/75 ratio throughout disbursements (i.e., we will not necessarily require the full 25% to have always been spent prior to any disbursements, nor will we allow any disbursements such that the government's risk at any point in time is greater than 75% of the project's cost); and
4. ERDA will foster the development of normal borrower-lender relationships.

We are currently processing the following applications:

PROJECT	LOCATION	LENDER	APPLICATION $M
Dry Creek Exploration (GRI w/Chevron Oil)	Geysers, CA	Bank of America	$ 7.500
GeoCal (GeoProducts)	Honey Lake, CA	Bank of Montreal	2.269
CU I Venture (GKI/McCulloch)	Beryl & Lund, UT Brawley, CA	Bank of Montreal	6.326
Southern Calif. Public Energy Corporation (City of Burbank)	Roosevelt Hot Springs, UT, and other sites	Dean Witter & Co.	25.00
Geothermal Food Processors, Inc.	Brady Hot Springs, NV	Nevada National Bank	3.460
Diablo Exploration, Inc.	New Mexico	Kidder, Peabody, Inc.	21.80
		TOTAL	$ 66.335

A number of other recent developments at the Federal level have very exciting potential for the geothermal industry. These include the President's National Energy Plan (NEP), proposed amendments to P.L. 93-410 passed by the House Science and Technology Committee, and a bill introduced into the House of Representatives by Congressman Barry Goldwater entitled "The Geothermal Steam Act Amendments of 1977."

In the NEP, the President has proposed a tax deduction for intangible drilling costs comparable to that now available for oil and gas drilling. Furthermore, "Additional funding will be provided to identify new hydrothermal sources which could be tapped for near-term generation of electricity and for direct thermal use. The Government will also support demonstration of direct, non-electric uses of geothermal energy for residential space conditioning and industrial and agricultural process heat in areas where this resource has not previously been exploited."

Several amendments to P.L. 93-410 were passed by the House Science and Technology Committee on May 11, 1977, which enhance the GLGP. Some highlights include:

1. Would allow guaranty to cover 75% of total costs of a non-electric or self-generation project when located near a geothermal resource predominantly for the purpose of using geothermal energy or its economic viability is dependent upon the performance of the geothermal reservoir;
2. Would raise the guaranty limits from $25 million to $50 million per project for non-electric applications and up to $100 million for electric applications, and from $50 million to $200 million per borrower;
3. Would allow interest differential payments for guaranties on taxable borrowing by states, municipal utilities or other political subdivisions of states, or Indian Tribes;
4. Would pledge the full faith and credit of the United States to the payment of guaranties;
5. Would allow interim payment of <u>principal</u> <u>and</u> interest to avoid defaults on worthwhile projects; and
6. Would provide for borrowing authority by the Administrator to rapidly meet default payments.

On May 5, 1977, Cong. Goldwater introduced a bill entitled "The Geothermal Steam Act Amendments of 1977." A few of the highlights are:

1. Would increase the per State acreage limitation on a geothermal leasehold from 20,480 to 51,200;
2. Would provide a statutory scheme to insure that geothermal leases will have access, on an equitable basis, to any transmission lines or rights-of-way for transmission lines on public lands in the general area of their leasehold; and

3. Would provide for environmental assessments in phases on federal geothermal leases.

In conclusion, several important strides have been taken which could enhance the development of the geothermal industry. One of these is the approval of the first loan guaranty application. However, the continued viability of the GLGP is still very much in question. With only seven applications received having a total of some $75.4 million versus an authorization of $200 million for FY 1977 and a request by ERDA for another $200 million in FY 1978, there are important voices asking two key questions:

1. Does the industry really want and/or need the GLGP? and
2. Does the industry really need $200 million per year?

To these questions, satisfactory answers can only be formulated based on numbers supplied by the industry.

Furthermore, if you have any suggestions on how we can improve the program - our procedures, the guidelines, etc., please let us know immediately.

It's up to you.

Sincerely,

Mark N. Silverman, Director
Office of the Geothermal
Loan Guaranty Program

Enclosure:
SAN News Release
No. 7747

INFORMATION FROM ERDA

San Francisco Operations Office 1333 Broadway Oakland, CA 94612

SAN NO. 7747
PHONE: (415) 273-4186

FOR IMMEDIATE RELEASE
MONDAY, MAY 9, 1977

The Energy Research and Development Administration (ERDA) has approved the first loan guaranty for a commercial geothermal energy project, a $9,030,000 guaranty to Republic Geothermal, Incorporated, Santa Fe Springs, California, and the Bank of America (Los Angeles).

Republic Geothermal, Incorporated, sought the guaranty on behalf of Republic - 1975 Geothermal Energy Drilling Program, a California limited partnership.

The company plans to drill and develop 11 new geothermal production and four reinjection wells in the East Mesa area of California's Imperial Valley, where it has been conducting exploratory operations since January, 1974. Three exploratory wells have been drilled previously by the firm to assess the reservior steam characteristics. Two of these wells showed an average steam output of about 2,800 kilowatts each and will be used as production wells, with the third unit serving as a reinjection well.

The Federal guaranty will cover 75 percent of the approximate 12 million total cost of the drilling project.

Steam extracted from the hot water geothermal resource could be sold commercially or used by Republic Geothermal for electric generation. The company has indicated it intends to build an electric power plant which could be operating by the early 1980s and would produce more than 36,000 kilowatts. The guaranty, however, covers only the cost of drilling and developing the geothermal wells.

(MORE)

"This first loan guaranty marks an important milestone in the Nation's program to accelerate greater use of geothermal resources," said Robert W. Fri, ERDA's Acting Administrator. "Implementation of this program is significant both in commercializing previous geothermal research and in the ultimate development of normal lender-borrower relationships."

ERDA's geothermal loan guaranty program was authorized by the Geothermal Research, Development and Demonstration Act of 1974 (P. L. 93-410), with a major provision to speed the commercial development and use of geothermal energy in an environmentally acceptable manner. The Act enables lenders to obtain Federal guarantees of loans for commercial development of geothermal energy resources.

"In this way, a lender's risk in financing commercial-scale geothermal operations is minimized," said Fri. "We hope this program will in time encourage the flow of credit for commercial geothermal development without the need for Federal assistance."

Dr. Robert W. Rex, President, Republic Geothermal, Incorporated, and Richard Manderbach, Senior Vice President, Bank of America, headed their organizations' preparation of the loan guaranty application. The application was submitted to ERDA's San Francisco Operations which is responsible for processing and evaluating all geothermal loan guaranty applications.

Currently, ERDA is evaluating six other applications for geothermal loan guarantees in Utah, New Mexico, Nevada and California.

* * *

We are revising our mailing list for those persons interested in receiving information on the Geothermal Loan Guaranty Program. If you would like to continue receiving material on the Program, please indicate below.

☐ YES

☐ NO

Please indicate any change(s) in address.

Thank You.

Mark N. Silverman
Geothermal Loan Guaranty
Program Specialist

UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
San Francisco Operations Office
1333 Broadway
Oakland, California 94612

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FACT SHEET

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
GEOTHERMAL LOAN GUARANTY PROGRAM

Legal Basis: Geothermal Energy Research, Development and Demonstration Act of 1974 (P.L. 93-410)

Purpose: Accelerate commercial development of geothermal energy by private sector through minimizing financial risk to lending agencies.

$ Limit:
Single Project - $25 Million
Single Borrower - $50 Million
Also -- 75% of aggregate cost of project but may be 100% of loan.

Interest: Not to exceed Administrator's determination (with Secretary of Treasury) of "reasonable" and "prevailing."

Terms: Up to 30 years or expected life of physical assets, whichever is less.

Location: Project in U.S., territories or possessions.

Termination: September 3, 1984, but guarantee agreements and interest assistance contracts in effect at that time will remain in effect.

Guarantee Fee: It is expected that no more than 1 per cent annually on average outstanding loan value, may be passed to borrower; however, a firm fee will be determined at a later date.

Controls and Restrictions: Detailed in Federal Register of May 26, 1976, pages 21433-21440.

1. Information concerning lender the borrower.
2. Information on project.
3. Interest assistance by ERDA.
4. Default authority by ERDA.
5. Permissible costs defined - criteria (financial considerations).
6. Expenses not allowable.
7. Environmental considerations.
8. Reports required and access to reports to other agencies.
9. Servicing the loan.
10. Visit access.
11. Withdrawal of guarantee.
12. Security (borrower's assets).
13. Patents and proprietary rights.
14. Escrow and interest.

Who Administers: The Administrator of ERDA; however, the Manager of SAN has been delegated the responsibility of processing all applications for geothermal loan guarantees from throughout the United States. After review and analysis of the application, the Manager will recommend approval or disapproval to the Administrator. Additionally, SAN has the responsibility of monitoring all loan guarantees throughout the life of the guarantee.

Where to Obtain Information: San Francisco Operations Office (SAN) of ERDA. Attention: Mark N. Silverman, 1333 Broadway, Oakland, CA 94612. Telephone: (415) 273-7881.

QUESTIONS AND ANSWERS ON ERDA GEOTHERMAL LOAN GUARANTY PROGRAM

GENERAL NOTE

Regulations were published on May 26, 1976. The Program is effective June 25, 1976.

PROGRAM PURPOSE

What is the purpose of the program?

To accelerate the commercial development of geothermal energy by the private sector by minimizing the financial risk to lenders.

PROJECT PRIORITIES

Will ERDA give priority to certain types of projects for the guaranty?

Yes. At this time, top priority will be given to those projects which will most quickly result in production of useful energy from geothermal resources. Others: projects which will utilize new technological advances or produce advanced technology components; projects that exploit potential of new geothermal resource areas. Lower priority: projects that propose exploration operations or acquisition of land or leases.

Ineligible:
1) if lender will make the loan at reasonable and prevailing rate of interest w/o guaranty.
2) projects that will consume rather than produce energy.

APPROPRIATION

Why didn't ERDA seek an appropriation this year?

We do not anticipate any defaults in FY 1976 and, therefore, did not seek an appropriation.

INTEREST RATE	What kind of interest rate? Reasonable and prevailing - as determined by the Administrator in consultation with Secretary of Treasury.
INTEREST ASSISTANCE	What if interest assistance is demanded this FY? ERDA may enter into a separate contract with the lender on interest assistance and this would specify the timing. Given no anticipation of defaults this FY, there would be no need for ERDA to step in.
DOLLAR LIMITATIONS	What are dollar limitations for the program? Maximum: \$25 Million - single project \$50 Million - single borrower 75% of total project costs (can equal 100% of the loan.)
PROGRAM SCHEDULE	When can we apply? Any time after June 25, 1976.
PROCESSING TIME	How much time will it take to get an application processed? Between 90-120 days, depending, of course, on lender process time and extent of environmental considerations.
HOW TO APPLY	How do we apply? The application and supporting documentation must be jointly submitted by the lender and borrower. A pre-application conference with both will be conducted by SAN. Either the lender or borrower should contact us whenever desired, but sometime before submission.

GIVEAWAY?	How will ERDA keep this from being a routine giveaway? The lender will be asked to identify why the guaranty is needed. The criteria are clearly detailed in the Regulations.
ERDA'S ROLE	What is ERDA's role? ERDA has been designated the federal agency responsible for implementing the program. The ERDA Administrator is authorized to guarantee lenders against loss of principal and interest on loans. The San Francisco Operations Office of ERDA is responsible for processing and evaluating all applications for the United States.
PROGRAM AUTHORIZATION	What is authorization for the program? Title II of the Geothermal Energy Research Development and Demonstration Act of 1974.
LOAN GUARANTY PERIOD	Does the 10-year life of the Act mean current loans can't carry past 1984? No. Loans can be guaranteed up to 30 years. It does mean that there will be no new guarantees past 1984.
MULTI-PHASE PROJECTS	Can we apply for phases of a project? Yes. Guaranty applications may be submitted for multi-phase projects in which borrower plans to utilize significant milestones as a basis of proceeding to next step.

REQUIRED INFORMATION

What kinds of data will be required for the application?

Most additional data requirements are detailed in Section 790.21 of the Regulations. Other requirements are detailed in the guidelines for loan applications.

COLLATERAL

What kind of collateral and what happens to it in event of default?

The collateral will be specified in the guaranty agreement. In event of default, the Attorney General of the U.S. will have no recourse to any assets of the borrower that are not in the agreement and not project-related. The objective is not to have borrowers go into bankruptcy.

PROJECT DEFINITION

How do you define "project"?

Tasks which, when completed, will result in an identifiable product, system, or component for which a market potentially exists. Examples: test and production drilling, power plant construction, equipment manufacturing, etc.

PROJECT COSTS

What will be considered acceptable project costs?

These are enumerated in the Regulations but, briefly, all reasonable and customary expenses paid by the borrower such as land purchase and/or lease payments, site improvements, drilling of wells, buildings, etc. Disallowed costs include company organizational expenses, certain overhead items, etc.

QUALIFIED BORROWERS

Who will be considered a qualified borrower?

Any public or private agency, institution, joint venture, association, corporation, individual (etc.) or other legal entity having authority to enter into loan agreement.

ENVIRONMENTAL CONSIDERATIONS

What kinds of environmental restraints will be imposed?

If public lands are involved, the Department of Interior will be responsible for assuring project compliance with the National Environmental Policy Act. ERDA will require the same standards for projects on state and private land, but these will be subject to the various State and local requirements.

ASSIGNMENT OF RIGHTS

Will ERDA permit assignment of rights to the guaranty?

No. Exceptions to this will only be made by the Manager of SAN. While shares can be made by the lender, we will only deal with the original lender.

DELAY DUE TO ENVIRONMENT

Will the guaranty be delayed pending en
mental clearance?

Environmental clearance will be requ
to ERDA's guaranty. To expedite pr
the application, the environmental
will be made concurrent with inter

UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
SAN FRANCISCO OPERATIONS OFFICE
1333 BROADWAY
OAKLAND, CALIFORNIA 94612

JUN 16 1976

DEAR GEOTHERMAL ENERGY DEVELOPER:

At long last, the Geothermal Loan Guaranty Program Regulations were signed on May 25, 1976, published in the Federal Register on May 26, 1976, and will become effective on June 25, 1976.

The enclosed Fact Sheet summarizes the key points in the Regulations. However, of major interest to you is the fact that the Manager of ERDA's San Francisco Operations Office (SAN) has the sole responsibility for processing all geothermal loan guaranty applications for the entire United States.

To work with you and process applications, SAN has established a Geothermal Loan Guaranty office. Assisting me are Dana Kilgore and Diane Nastich, plus several others in SAN.

The Application Form by itself will not meet SAN's requirements. Many of the kinds of additional data and documentation needed are outlined in Section 790.21 of the Regulations; however, more specific information will be contained in guidelines now being developed by SAN. These guidelines will clearly spell out the additional data SAN will need to process a loan guaranty.

SAN also is developing the internal procedures it will use to process each application as thoroughly and quickly as is responsibly possible. However, SAN must perform environmental, financial, legal, management/marketing, and technical/geophysical assessments of each application.

Therefore, the average projected review time is currently estimated to be about eighty (80) working days. Some applications will take less time, others more, depending on their complexity, location of project and completeness of data submitted.

To further insure that borrowers and lenders fully understand all requirements, SAN will conduct a pre-application conference with applicants for each proposed project prior to submission.

For your information, SAN will also conduct a one-day seminar in Los Angeles on June 22, for lending institutions only. The purpose of the seminar is to more fully explain to prospective lenders both the program and the procedures SAN will follow.

If you have a possible project in mind, we would appreciate receiving a very brief summary of it; to include scope, location, estimated cost, and projected date of application.

Please feel free to call (415-273-7881), write, or come by and see us, if you have any questions.

We look forward to working with you in helping to develop geothermal energy as a supplemental power source to meet our Nation's energy needs.

Sincerely,

Mark N. Silverman
Geothermal Loan Guaranty
Program Specialist

Enclosure:
Fact Sheet

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Miller, K. R. and Elders, W. A., "Petrology, Hydrothermal, Mineralogy, Stable Isotope Geochemistry, and Fluid Inclusion Geothermometry of LASL Well C/T-1 (Mesa 31-1) East Mesa Geothermal Field, Imperial Valley, California," Los Alamos Scientific Laboratory report (in progress), 1980.

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GEOTHERMAL MARKETING

▸EDUCATION

▸PERSUASION

▸ADOPTION

WESTERN ENERGY PLANNERS, LTD.

GEOTHERMAL MARKETING

ISSUES

*** IN MARKETING, USER NEEDS ARE PRIMARY CONCERN ***

- Availability of geothermal energy is not sufficient to cause colocated energy users to adopt it or non-colocated energy users to move to a resource.

- For colocated users, geothermal energy must be advantageous, for such reasons as:

  1. Cheaper
  2. Better
  3. More abundant
  4. More convenient

- For non-colocated users, the area or site must offer advantages to the prospective user. It must satisfy such needs as:

  1. Market
  2. Labor force
  3. Transportation
  4. Raw materials
  5. Desirable living environment for professional or executive staff
  6. Institutional incentives

GEOTHERMAL MARKETING

ISSUES (CONT'D.)

- MARKETING ACTIVITIES ARE FOCUSED TWO WAYS:

  1. ON-SITE: EXISTING FACILITIES, DEVELOPERS OR USERS COLOCATED WITH GEOTHERMAL ENERGY.
  2. OFF-SITE: INDUSTRIES, UTILITIES, COMMERCIAL FACILITIES OR RESIDENTIAL DEVELOPERS THAT MIGHT LOCATE WHERE GEOTHERMAL ENERGY IS FOUND.

- THE TWO TYPES OF ACTIVITIES REQUIRE DIFFERENT STRATEGIES, THE ON-SITE ACTIVITIES SHOULD BE THE STARTING POINT.

- IT IS IMPORTANT TO RESPECT OTHERS' TURF. THEREFORE, NEED TO WORK THROUGH AND WITH LOCAL ELECTED AND APPOINTED OFFICIALS AND OTHER STATE OFFICIALS AS APPROPRIATE.

- TO TRANSFER TECHNOLOGY (OR ANY INNOVATION) REQUIRES MORE THAN EDUCATION. THE PROCESS MUST INCLUDE PERSUASION AND ADOPTION.

  ATTITUDES MAY LEAD THROUGH SEVERAL STEPS, SUCH AS:

  1. AWARENESS
  2. KNOWLEDGE
  3. INTEREST
  4. PREFERENCE
  5. INTENTIONS
  6. SATISFACTION
  7. COMMITMENT
  8. IMPLEMENTATION

GEOTHERMAL MARKETING

ISSUES (CONT'D.)

- To complete the full cycle from awareness to implementation requires working with prospective developers and users to assist them through the entire process if necessary, either directly or indirectly. The information they need includes:

  1. General information about geothermal energy, its uses and techniques for use.
  2. Development procedures
  3. Economic feasibility of the site and proposed use
  4. Engineering techniques for site and proposed use
  5. Resource Evaluation
  6. Financing sources - investors, loans, grants
  7. Institutional requirements
  8. Environmental requirements

GEOTHERMAL MARKETING

STRATEGY

- Collaborate with state and local officials and agencies

State

  - Economic Development
  - Energy Impact
  - Local Development
  - Professional and trade associations
  - Others (state-specific)

Local

  - City & County Officials
  - Chambers of Commerce
  - Economic Development
  - Professional & Trade Associations
  - Individual Businesses

- Identify goals
- Develop targets
- Conduct activities

GEOTHERMAL MARKETING TOOLS

- Studies
  - Area Development Plans
  - Site Specific Development Analyses
  - Time Phased Project Plans
  - Institutional Handbooks
  - Engineering and Economic Feasibility Studies
  - Demonstration Project Evaluations
  - Other Reports
- Programs
  - PRDA Feasibility Studies
  - PON Demonstration Projects
  - Geothermal Loan Guaranty Program
  - Reservoir Confirmation Drilling Program
  - Technology Development
  - Federal Funding Programs
  - Regional Commissions
  - User Assistance (UURI, EG&G, NMEI)
  - NMEI Site Specific Analyses
  - Other

GEOTHERMAL MARKETING

APPROACH

COLOCATED FACILITIES

- Target

  Review lists of communities, industries and utilities colocated with identified geothermal resource sites

  Note those industries that have process heat requirements less than 400° F from list provided by WEPL.

  Choose best sites to work with first - using your criteria or WEPL's.

GEOTHERMAL MARKETING

APPROACH

COLOCATED FACILITIES (CONT'D.)

- EDUCATE COMMUNITY, INDUSTRY, UTILITY

1. BROCHURES

   PREPARE AND SEND TO SCHOOLS, COLLEGES, ENERGY FAIRS, ENERGY OFFICES, OTHER STATE OFFICES, LOCAL GOVERNMENTS, PROFESSIONAL AND TRADE ASSOCIATIONS, FIRMS (EG. A & E FIRMS), UTILITIES.

   SHOULD SAY:
   - WHAT AND WHERE GEOTHERMAL ENERGY IS IN YOUR STATE
   - WHAT AND HOW IT CAN BE USED
   - WHO TO SEE FOR INFORMATION
   - OTHER

2. NEWSLETTERS

   TO SAME AUDIENCE AS ABOVE (NO. 1).

3. NEWS RELEASES

   TO NEWSPAPERS, TV STATIONS, RADIO, REGARDING MAJOR GEOTHERMAL ACTIVITIES AND TO ENCOURAGE GENERAL STORIES ON GEOTHERMAL.

GEOTHERMAL MARKETING

APPROACH

COLOCATED FACILITIES (CONT'D.)

4. Talks to:

   Fairs

   Civic organizations

   Professional organizations

   Trade associations

   City Council

   Chambers of Commerce

   Jaycees

   Colleges and universities

   General public

   First talk to group, cover such items as nature of geothermal, how used, developed, state program, then tailor items to specific group.

5. Special articles for:

   Professional magazines

   TRADE MAGAZINES

   OTHER

GEOTHERMAL MARKETING

APPROACH

COLOCATED FACILITIES (CONT'D.)

- Persuade community, industry, utility

  Provide or arrange for user assistance, both as requested and in advance of requests, such as:

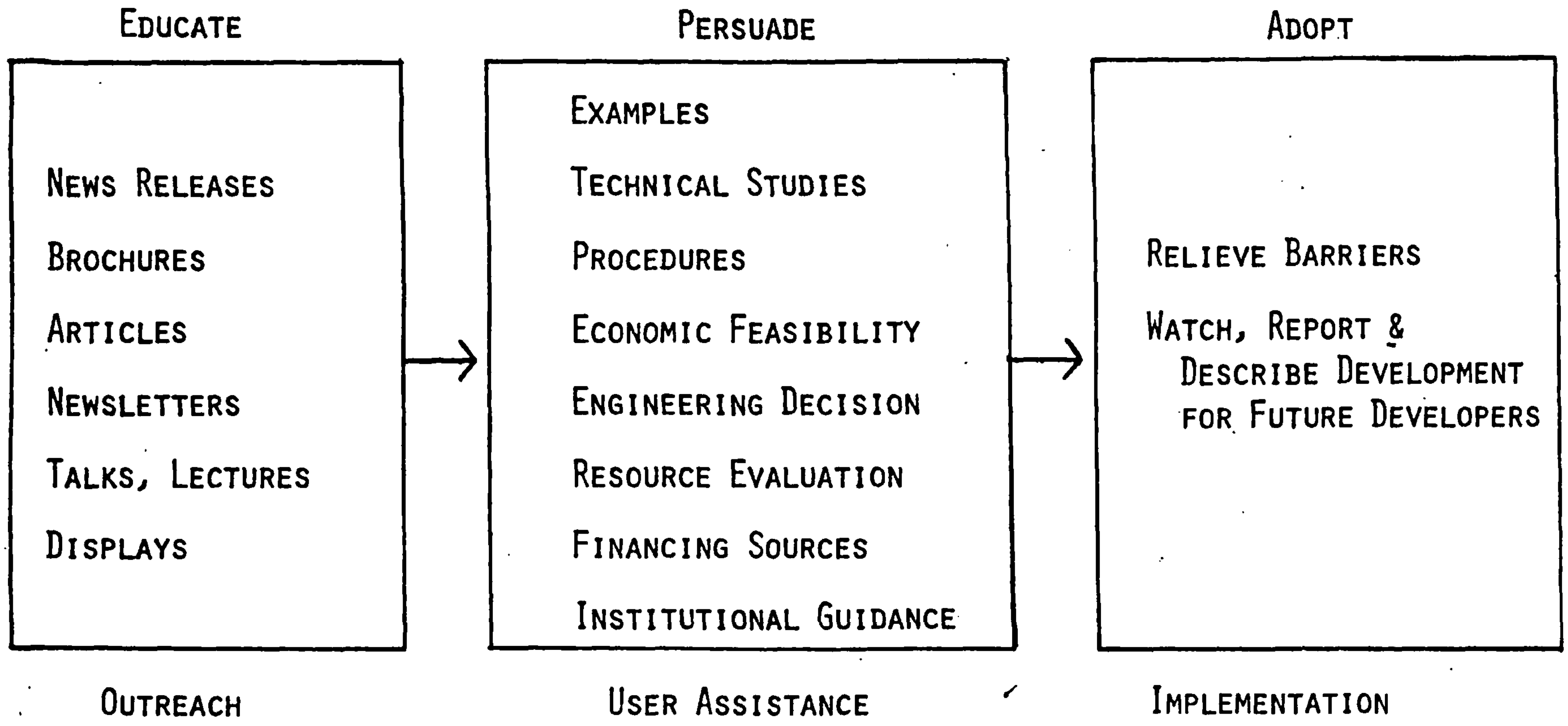
  - Examples of similar uses, technical studies
  - Development procedures, guidance
  - Economic feasibility study
  - Preliminary engineering design
  - Resource evaluation
  - Financing source suggestions and information
  - Institutional guidance

- Help Implement

  1. If barriers arise, help remove them.
  2. Finally, watch, report and record development for helping others in future.

  Remember: The test of success is geothermal energy on-line.

GEOTHERMAL MARKETING PROCESS



EDUCATE

- NEWS RELEASES
- BROCHURES
- ARTICLES
- NEWSLETTERS
- TALKS, LECTURES
- DISPLAYS

OUTREACH

→

PERSUADE

- EXAMPLES
- TECHNICAL STUDIES
- PROCEDURES
- ECONOMIC FEASIBILITY
- ENGINEERING DECISION
- RESOURCE EVALUATION
- FINANCING SOURCES
- INSTITUTIONAL GUIDANCE

USER ASSISTANCE

→

ADOPT

- RELIEVE BARRIERS
- WATCH, REPORT & DESCRIBE DEVELOPMENT FOR FUTURE DEVELOPERS

IMPLEMENTATION

GEOTHERMAL MARKETING

APPROACH

NON-COLOCATED

- Target

  1. Review industry location criteria to identify possible industries

  2. Discuss with state, local, private economic development groups to:

     A. Identify economic development goals - locations, types of industries

- Educate

  1. Tell above groups about geothermal energy, its location, uses, techniques for development

  2. Ask how can help them incorporate geothermal energy availability into their promotional packages

- User Assistance

  Be available to provide:

  1. Examples of similar uses, technical studies
  2. Development procedures, guidance
  3. Economic feasibility study
  4. Preliminary engineering design
  5. Resource evaluation
  6. Financing source suggestions and information
  7. Institutional guidance

Geothermal Geophysics

During the interval Aug. 24 through Aug. 28, 1975, a workshop on *Geothermal Methods Applied to Detection, Delineation, and Evaluation of Geothermal Resources* (GMADDEGR) was held at Snowbird, Utah. Snowbird Resort, at the blue sky altitude of 8100 foot (2470m) elevation, in the Wasatch Mountains is a 30 minute drive from central Salt Lake City. At Snowbird, rented condominiums amidst pine, quaking aspen and granite provide a restful atmosphere for full-day workshops of this type. Cuisine in Little Cottonwood Canyon, in which Snowbird nestles, is superb.

Given these ethereal surroundings and an unprouncable acronym, 51 participants and observers energetically immersed themselves in a program designed (casually on purpose) by a Steering Committee consisting of D.M. Boore (Stanford), J. Combs (U.T.D), W.M. Dolan (AMAX), B. Greider (Chevron), D.R. Mabey (ex officio of USGS), H.F. Morrison (U.C.B), and myself as General Chairman. The U.S.G.S. (technical monitor D.L. Klick) financed the workshop while the University of Utah (the writer as Principal Investigator) organized the workshop. Participation in the workshop was restricted to 47 participants selected by the Steering Committee and 4 observers selected by the U.S.G.S. One other observer and several invitees were unable to attend. Balanced representation between industry, government, and academia was stressed at every turn.

The principal points of the Guidelines for the Workshop, issued in advance, follow:

"1) The morning sessions are expected to portray an inventory of current knowledge of applications and to provide an identification of known problems and points of controversy.

2) For each morning session, a *Session Chairman* and a commit-

tee have been appointed. They have the responsibility for assembling current knowledge and presenting it to the participants. It is suggested that the *Session Chairman* present a half-hour overview, with his committee members, or others, contributing differing viewpoints in 5-10 min. presentations. The presentations should be interspersed with discussion. Individuality in design of each session is encouraged. The session chairman is responsible for stimulating discussion in the morning.

3) It should be assumed that every participant has a basic understanding of all methods so that no tutorials are necessary.

4) The participants will be divided into six groups of seven or eight for the afternoon group discussions. A random selection process will be used each day to select the groups for that afternoon. Each group will elect it's own *Group Leader* who will debate the morning session with his group, and identify current problems and controversies, forcast future developments (speculation should be made in a critical fashion) and give a 10 min. viewgraph presentation in the evening. The *Group Leaders* are responsible for stimulating discussion in the evening.

5) Session Chairman will be expected to write a three to six page summary of each morning session, including presentations and discussion. This summary is to be prepared in the afternoon of each day.

6) Group leaders will be expected to write a one to three page summary discussion at each afternoon group discussion.

7) A special two man task force of D.L. Klick & L.J.P. Muffler has been assigned to write summaries of each evening discussion.

From the above reports I have drawn the following observations.

Models of geothermal systems are still very much in the conceptual stage. There are not, at this writing, any unifying concepts that tie together models for any of the known geothermal systems. It would appear, however, that necessary ingredients for continental convection-dominated systems include: a shallow young (<1 MY?) silicic intrusive to serve as a source of heat, a fracture dominated reservoir, a cap rock or a self-sealing fracture system, and adequate recharge. Where regional heat flow is exceptionally high, such as might exist in the Basin and Range physiographic province, a shallow intrusive may not be necessary if the fracture system and convection within it both extend to sufficient depth. The above two models were the basis for most of the discussion at the workshop, with only brief reference being made to *hot dry rock, warm water, geopressured interplate melting anomaly, and spreading ridge systems.*

A *hot dry rock* system, is one through which fluid would be circulated to form a heat exchanger. Los Alamos Scientific Laboratory (LASL) has drilled into precambrian gneiss and amphibolite just west of the Valles caldera, Jemez Mtns., New Mexico. At depths of 9000 feet permeabilities are very low and temperatures are near 200°C. LASL clearly has found "hot dry rock" but the technology for fracturing and heat extraction has not been demonstrated.

The Energy Research and Development Administration (ERDA), with cooperation from the United States Geological Survey (USGS) is attempting to develop in the Raft River Valley, Idaho, a heat exchanger in a low-temperature (147°C) convective hydrothermal system with a very strong artesian flow of water.

Geopressured systems, with the diagnostics of excessive pore fluid pressure, higher than normal temperatures, and methane dissolved in the fluids, offer a unique possibility for energy development, particularly in the Gulf Coast.

The Hawaiian intraplate melting anomaly offers recent volcanoes and molten magma at shallow depth as sources of heat.

The Icelandic oceanic spreading ridge has long been exploited for central heating.

The design of optimum geological/geochemical/geophysical exploration sequences suited to detection, delineation, and evaluation of convective geothermal systems stirred much debate. There were as many approaches to exploration as there were participants in the workshop! A typical, phased exploration sequence, however, would be as shown in Table 1. Flexibility in utilizing such a modular exploration sequence was stressed. Given such a broad array of geological, geochemical, and geophysical modules to be used, it is important to understand what each module contributes. Participants in the Workshop were in general agreement on the contributions listed in Table 2. Beyond the methods listed in Table 2, *detection of earth noise* and *remote sensing* techniques were considered to offer little at the present time. It was noted that the areal distribution of microearthquakes relative to a geothermal resource was usually not simple nor simply understood. No agreement could be reached on the "best" method or the best combination of methods for obtaining a three-dimensional resistivity distribution in a geothermal environment. Considering the variety of techniques available, e.g., bipole-dipole resistivity, dipole-dipole resistivity, active electromagnetics, MT/AMT, and tellurics, and considering the difficulty of obtaining objective comparisons, the writer is not at all surprised at this result of the workshop. The self-potential method received divided support.

Geophysical problems clearly identified for further research included 1) establishment of realistic models of coupled hydrothermal - magma systems, 2) systematic collection of world-wide case histories, 3) determination of permeability and temperature at depth from surface measurement, 4) increased emphasis on quantitative evaluation of the various electrical methods, 5) means for assessing the relative importance of salinity, porosity, alteration, and temperature in producing resistivity lows, 6) laboratory determination of physical properties under geothermal conditions. 7) development of logging techinques in deep wells in which temperatures exceed 200°C, 8) multiple data set inversion, 9) means for direct detection of partially molten or molten magma chambers, 10) evaluation of seismic attenuation in geothermal areas, 11) analog and numerical studies of earth noise and microearthquake generation, 12) the meaning of the Curie point isotherm, 13) more published studies on seismic techniques, both active and passive, 14) research on the self-potential method as a possible specific indicator of geothermal resources, 15) gravity and leveling surveys to determine percentage recharge of a reservoir, 16) nature of fractures and depth to which they extend, 17) interpretation of high regional heat flow, 18) quantitative enhancement of signal to noise in remote sensing, 19) and the importance of refraction in conductive heat flow.

The most important comment heard at the conclusion of the workshop was that "I learned a lot". We hope so for there is much to be learned.

Stanley H. Ward
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University of Utah
Salt Lake City, Utah 84112

TABLE 1

EXPLORATION ARCHITECTURE

PHASE I	·Office Study
	·Age Dating of Silicic Intrusives & Extrusives
	·Geologic Reconnaissance
	·Collection and Aanlysis of Thermal Water Samples
	·Thermal Gradient Measurements in Available Holes
	·Assessment of Ground Water Recharge
	·Aeromagnetic Survey
PHASE II	·Drill about 20 Thermal Gradient Holes to 40m
	·Measure Thermal Gradients & Calculate Heat Flow
	·Telluric Survey
	·Resistivity Survey
	·Detailed Geology
	·Alteration Studies on Cuttings from Drilled Holes
PHASE III	·Microearthquake Monitoring for 30 Days Minimum
	·Determine Mercury in Soils
	·Gravity Survey
PHASE IV	·Drill Model Testing Holes to 600m
	·Temperature Log
	·Measure Pressures
	·Determine Chemistry of Water
	·Study Alteration of Cuttings
	·Describe Lithology
	·Estimate Fracture Porosity
PHASE V	·Production Test

TABLE 2

GEOPHYSICAL METHODS

	Contribution in the Convective Geothermal Environment
Gravity	-Delineation of structural framework -Detection of hot intrusive -Delineation of self-sealing silica deposit
Magnetics	-Delineation of structural framework -Delineation of zone of magnetite destruction -Location of igneous rocks related to heat source -Mapping Curie Isotherm within intrusive serving as heat source (magma chambers?)
Microearthquake Monitoring	-Direct mapping of active zones of fracturing -Seismic delay mapping of bodies of anomalous velocities (magma chambers?) -Stress distribution from fault-plane solutions
Resistivity	-Fluid salinity, rock porosity, alteration, and elevated temperatures all tend to produce resistivity lows in a geothermal environment.
Heat Flow	-Anomalous thermal gradients and heat flow can be detected readily in shallow drill holes using thermistor probes.

LIST OF PARTICIPANTS

James K. Applegate
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David D. Blackwell
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David Boore
Tom Box
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George R. Jiracek
Richard L. Jodry
Robert L. Kovach
Martin Kane
Paul Kasameyer
Donald Klick
James B. Koenig
Arthur H. Lachenbruch
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Arthur Lange
H. Frank Morrison
Don R. Mabey
Tsvi Meidav
L.J. Patrick Muffler
Thomas McEvilly
Terry Offield
Alan O. Ramo
Jack Sanders
William Sill
Morris Skalka
Robert B. Smith
G.G. Sorrells
Paul Storm
Chandler Swanberg
George Thompson
Ron Toms
John Tsiaperas
David L. Williams
Ronald Ward
Stanley H. Ward
S.H. Yungul

GEOLOGICAL INVESTIGATIONS

Purpose

The purpose of the geological investigations is, of course, to develop a model concordant with the outcrop pattern and known hot-spring activity that can be used as a base to evaluate the prospect.

In areas like Roosevelt, where abundant outcrops occur, the geological model can provide data to assist in geophysical interpretation. The Geophysical data then, in turn, modify the interpretation based on surface outcrop, and greatly increase the vertical dimensions of the model.

Ultimately, by comvining geological and geophysical data in several different areas, it is hoped that several "type" models can be developed to assist in evaluating blind prospects (those concealed by alluvium), by geophysical data alone.

Scope

Geologic studies have or will include the following:

1. Mapping
    (a) lithology, and
    (b) structure.
2. Petrologic studies

3. Alteration studies

4. Geochemical studies

5. Geochronological studies

6. Hydrologic studies.

Each of these is discussed separately below.

Mapping

Background: Theses by Earll (1957) and Liese (1957) described and mapped the Mineral Range in the area just to the east of the hot spring area. Maps were on uncontrolled aerial photographs.

The first modern description of the hot-spring area is in Mundorff (1970, p. 42).

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GEOLOGICAL INVESTIGATIONS

Purpose

The purpose of the geological investigations is, of course, to develop a model concordant with the outcrop pattern and known hot-spring activity that can be used as a base to evaluate the prospect.

In areas like Roosevelt, where abundant outcrops occur, the geological model can provide data to assist in geophysical interpretation. The Geophysical data then, in turn, modify the interpretation based on surface outcrop, and greatly increase the vertical dimensions of the model.

Ultimately, by comvining geological and geophysical data in several different areas, it is hoped that several "type" models can be developed to assist in evaluating blind prospects (those concealed by alluvium), by geophysical data alone.

Scope

Geologic studies have or will include the following:

1. Mapping
    (a) lithology, and
    (b) structure.
2. Petrologic studies

3. Alteration studies

4. Geochemical studies

5. Geochronological studies

6. Hydrologic studies.

Each of these is discussed separately below.

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GEOTHERMAL POTENTIAL 1978

B. Greider
Vice President IEC
May 17, 1978

Dr. Stan Ward.
University of Utah Research
Institute
391 Chipeta Way Suite A
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84108

Interest in using the heat of the earth to provide an indigenous source of energy has begun to increase almost as rapidly as energy bills in the United States. Natural resource development companies and groups of investors are increasing their exploration for accumulations of heat that can be used in electrical generation, space heating and cooling, agriculture, and industrial process heating.

Developers expect the natural sources of heat above 450° F in the western United States to produce electricity at prices competitive with low sulfur coals shipped from the Powder River basin of Wyoming to the electricity generating centers supplying western Nevada and California. Water within the low energy 150° F temperature range can provide processing heat, if the source is in a location where the energy can be used in the U.S. It is expected that sulfur limits for fuel oil will be set similar to coal. To meet such standards, additional investment and costs will be required to prepare acceptable fuel. With such increases in cost, new uses for geothermal heat (energy) will become practical. When that happens, more people will become interested in joining the exploration search to find and develop new deposits of heat for production of energy.

The development of a geothermal reservoir is capital-intensive, requires expert planning, and long times from initial expenditure until positive income is achieved. The utilization of a developed project requires extensive engineering, approximately two years in negotiation with governmental agencies, and a lot of money.

The costs of maintaining and operating the producing fields is about four to five times greater than the capital investment. An important portion of this cost is associated with the injection system that collects the water after the heat is removed and then returns it to the subsurface reservoirs. Reducing these costs is an essential objective if geothermal is to be competitive with other fuels.

Countries with high fuel costs and geothermal sites are now developing a wide variety of geothermal plants. Japan appears to be building the most efficient flash systems for use in hydrothermal areas rimming the Pacific Ocean.

The assessment of geothermal energy resources by considering this energy to simply be the heat of the earth provides estimates of gigantic size. Useful geothermal reserve assessment requires professional analysis. The goal is to determine how much heat can be produced at a useful rate and temperature for at least twenty years from one area. This demands a

Dear Stan:
Most of this is old hat to you. This is the basic format of the presentation I made at the GRC short course for the Wash. D.C. workers.
Regards Bob.

thorough understanding of the manner in which heat is transported to areas of accumulation, how it accumulates, the methods and costs to find, produce, and convert to a useable form of energy. With those studies in hand, a person can then determine what part of this resources can be sold in competition with other fuels and thereby establish the size of the reserve.

Accessments of the supply of geothermal energy have been published by government agencies, private companies, universities and inter-governmental agencies such as the United Nations. These estimated supplies have been prepared in megawatts per year, joules per year, giga watt centuries, giga calorie centuries, per cent of the national energy budget, the equivalent bbl(s) of oil, and per cent electricity generated per year.

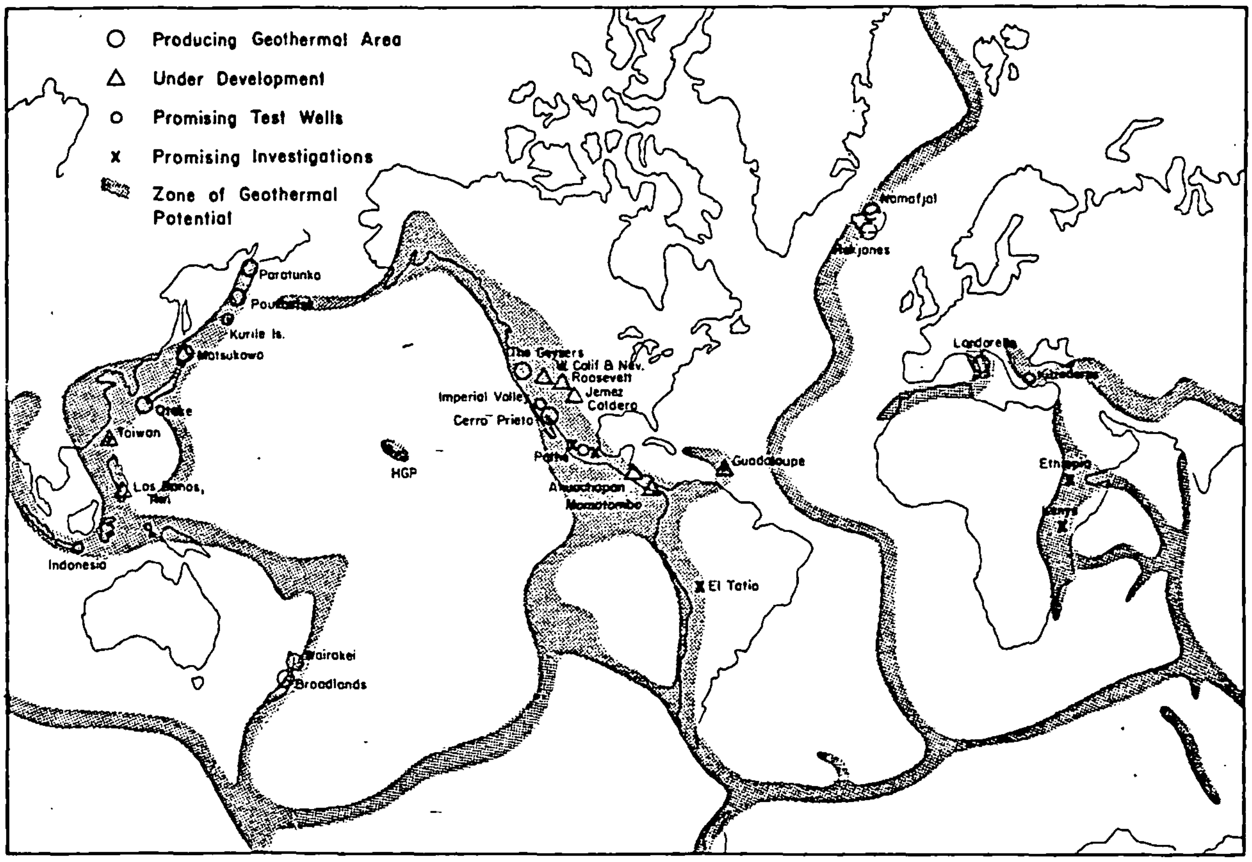
The supply has been related to all the heat present above an arbitrary temperature datum, the amount of heat between certain temperature levels, that heat contained in producing water, and that heat contained in the rock framerock transferred to the moving body of water, and the amount that could be produced if the government would provide various incentives.

These incentives have included tax credits, deductions in tax calculations, investment tax credits, rapid depreciation, and extensive depletion allowances. Other incentives include aid in exploration, aid in developing, engineering of generating plants, financing of generating plants, and reservoir engineering studies. Very little has been prepared showing the increased benefit to governmental programs, including tax revenue by demonstrating the increased flow of dollars from projects that would become profitable with this aid compared to project tax revenues that would be commercial without this aid.

The actual potential of geothermal energy is affected by how the resource and reserves are calculated. These calculations must consider availability and application of the governmental incentives, the price of other energy sources, versus the market price of geothermal energy, and the reliability of the production forecast. The size of required investment, and the expected profit generated by those investments, plus the availability of lands to explore will be the motivating forces in determining the true potential of geothermal energy development in the United States.

The most important factor in converting any resource into a reserve is how the individuals that are actively dedicated to discovery and development, attack the problem. The key to successful reserve development is the quality of the people assigned to the task.

A casual examination of geothermal areas of the world, shown in figure 1, will allow even the uniniated to estimate the supply of geothermal energy that is presently useful in the generation of electricity. The world's total geothermal generating capacity in development and developing projects with significant reservoir testing, is approximately 2,600 megawatts. The potential areas identified by preliminary investigation of sufficient extent to allow analogies with development areas is estimated to have an additional 12,000 megawatts of indicated reserves. Inferred reserves of an additional 20,000 megawatts of electricity capacity may be developed within the next 20 years. The existence of geothermal energy does not assure the resource will be converted to a reserve. In a free economy the competition in the market place and the return on the potential investment will determine if and when these resources will become useful.



GEOTHERMAL POWER DEVELOPMENT

MAP 1

BG
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The United States has the greatest producing capacity in the world at this time. The Geysers in northern California produces and has more capacity building than any other commercial producing geothermal country in the world. Those areas capable of commercial production or that have commercial plants under engineering design are listed in Table I.

Table I

World Geothermal Generating Capacity

In Megawatts

Country	Area	Operating Capacity	Engineering & Construction
U. S. A.	The Geysers	502	450
	Roosevelt	- -	80 110
	Heber	- -	~~110~~
	E. Mesa	- -	60
	Other	- -	200
Italy	Larderello	385	
	Travale	15	
	Mt. Amiato	22	
New Zealand	Wairakei	150	
	Broadlands		165
	Kawerau	10	
Japan	Matsukawa	20	
	Otake	13	55
	Onuma	10	
	Oninobe	25	
	Hatchobaru		55
	Takinow		55
Mexico	Cerro Prieto	75	75
	Pathe	3.5	
El Salvador	Ahuachapan	35	60
Nicaragua	Momotombo		30
Iceland	Namafjell	2.5	
	Krafla		55

Table I (cont.)

World Geothermal Generating Capacity

In Megawatts

Country	Area	Operating Capacity	Engineering & Construction
Phillipines	Tiwi		100
USSR	Pauzhetsk	5	
	Paratunka	1	
Turkey	Kizildere		2.5
	TOTAL	1274.0	1552.5

Geothermal energy properly located may be useful for its contained thermal energy without being converted to electricity. In many geothermal areas of the world, this is the simplest and cheapest source of energy. Interest in using this source of energy is directly related to the need for local thermal energy, and the cost of other sources of heat. Space heat and cooling, industrial processing, and agricultural uses are the most significant uses of this fuel. The present non-electrical use of the contained thermal energy in geothermal areas of the world is about 7,000 MW thermal or 5 X 10^{14} J/D. This is equivalent to the BTU content of 105,000,000 bbl(s) of oil per year.

EPRI this year estimated non-electrical uses of geothermal energy in the world should be about 20,000 megawatts thermal within the next 10 years. If this comes to pass, the thermal equivalent of approximately 148,000,000 bbl(s) of oil per year can be saved. This appears to be worth pursuing as the potential use is 200 to 300 times this projected use.

GEOTHERMAL PRINCIPLES

A quick review of the heat principles involved in geothermal development will provide the foundation for assessing the value of geothermal energy accumulations. Heat is the energy contained in a body whose molecules are in motion. When heat is transferred from one substance to another, energy is transferred to that substance. Heat flow is a measure of the amount of heat (energy) being transferred from a substance of higher temperature to a substance of lower temperature.

If a well is drilled into a fluid-saturated system, the heat is transported from the rocks to the well bore by either vapor (steam) or liquid. There must be sufficient horizontal and vertical permeability to allow the fluid to move easily. A 6,000 ft. to 8,000 ft. well must sustain flow rates of more than 100,000 lbs. of steam per hour, or 500,000 lbs. of water (above 325° F) per hour for 20 to 25 years to be considered commercial for electricity generation. Direct use of heat for industrial heating or space heating and cooling does not require such high heat output. The lower temperatures for such uses can be found in a greater number of anomalies, however, their usefulness is dependent upon low costs being achieved in development and production.

The geologic model that is generally accepted by geothermal explorers and developers (Figure 2) has three basic requirements to function:

1. A heat source (presumed to be an intrusive body) that is above 1200° C and within 16 Km of the surface.
2. Meteoric waters circulating to depths of 10,000 ft. - 20,000 ft. where heat is transferred from the conducting impermeable rocks above the heat source.
3. Vertical permeability above the heat source connecting the conducting rocks with a porous permeable reservoir that has a low conductivity impermeable heat retaining member at its top.

Water, expanding upon being heated, moves buoyantly upward in a hot concentrated plume. Cold waters move downward and inward from the basin's margins to continue the heat transfer process. Heat is transported by convection in this part of the model.

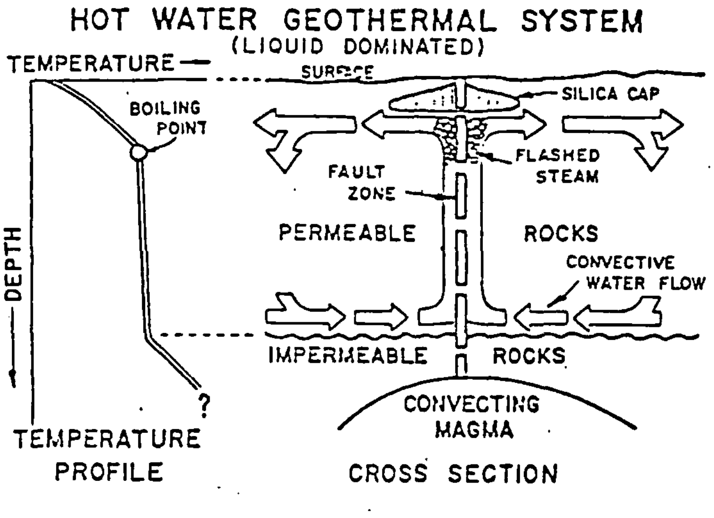

Fig. 2 — Geological Model of a Hot Water Geothermal System (after White, 1973).

Geologic investigation is the necessary ingredient that makes all other techniques useful. Broad reconnaissance of the surface data integrated into subsurface data is used to find an area of general interest. The ingenuity of the prospect finder in using data available to all workers determines whether an exploration program moves into advanced stages of using the proper combinations of the above methods. Geologic interpretation of the data acquired may justify the money required for exploratory drilling. The results of the drilling must be integrated into the geologic investigation to determine if a promising prospect is present.

The investigation must establish that:

1. High heat flow or strong temperature gradients are present at depth.
2. The geology provides reasonable expectation that a reservoir sequence of rocks is present at moderate depths from 2000' to 6000'.
3. The sequence of rocks offers easy drilling with minimal hole problems.
4. A high base temperature and low salinity waters as indicated by geochemistry of water sources should be present. The surface alteration and occurrence of high heat flow should cover an area large enough to offer the chance for a field capacity of more than 200 MW.

Interpretation of geochemical data requires professional skill in geology and chemistry. If the geology is well known, useful information can be developed.

Geophysical surveys are useful in predicting the general area and depth of high temperature rocks and water. Rocks at depth are better conductors of electricity (natural and induced currents) when there is an increase in temperature, an increase in porosity, an increase in clay minerals, or an increase in salinity in their contained fluids.

Table I from C. Heinzelman's presentation of October 15, 1977, illustrates exploration techniques and associated costs. The overall amount of money (per successful prospect) required is 2.5 million to 4.75 million 1977 dollars. This provides for limited failure and follow up costs, but does not include the other exploration failures and land costs.

Table I

EXPLORATION TECHNIQUES & APPROXIMATE COSTS

Objective	Technique	Approximate Cost ($)
Heat Source & Plumbing	Geology	$ 15,000
	Microseismicity	15,000
Temperature Regime	Gravity	20,000
	Resistivity	25,000
	Tellurics & sagnetotellurics	40,000
	Magnetics	15,000
	Geochemistry (Hydrology)	12,000
	Temperature Gradient 20 holes	100,000
	Stratigraphic Holes (4)	160,000- 240,000
Reservoir Characteristics	Exploratory wells (3)	1,800,000-4,000,000
	Reservoir test	250,000
Total to Establish a Discovery		$2,472,000-4,752,000

This is probably the minimum expenditure to move a portion of the resource into a reserve.

Upon deciding that a significant geothermal anomaly exists, the rate of engineering expenditures must increase rapidly to determine whether the development can proceed. Essentially, there are no set figures for what it costs to develop a geothermal field. The basic reason for this is that each depends upon engineering the development to be compatible with the geology of the accumulation, and the requirements of the electricity generating system. The electricity generating system must be designed within the constraints of available temperature, rate of production, and ambient conditions of the field site. The key variables are:

1. Temperature of the fluids produced.
2. Composition of the reservoir fluids.
3. Composition of surface or near surface fluids.
4. Geology of the reservoir framework.
5. Flow rates that can be sustained by the reservoir.
6. Cost of drilling in the prospect area.
7. Well spacing and geometry of the producing and injection sites.
8. Turbine system to be used.
9. General operating costs in the area.

Test Wells - Thermal evaluation requires the drilling of test holes. Heat flow and temperature gradient evaluation requires drilling to intermediate depths. Confirmation drilling requires holes drilled to the actual reservoir for diagnostic evaluation.

Heat flow and temperature gradients measured in the upper 100 to 500 ft. depth are useful in describing the area where the heat transfer is most intense. When mapped, these do give a qualitative analysis as to the location and shape of the hottest near-surface heat accumulation. Linear projection of temperatures obtained near the surface cannot be used to predict the temperatures that will be encountered 2000-3000 ft. below the surface, even if the section below has a uniform lithology and the geothermal graident is a straight slope. The temperature for a fluid-saturated system cannot be projected to a maximum above that for boiling water at the pressure calculated for the depth of projection. At some point along the boiling point curve, the temperature of the system may become isothermal and the rocks and fluids will have the same temperature for many hundreds of feet deeper. The rock temperature may decrease as a hole is drilled deeper if the hole is on the descending edge of a plume of hot water or merely below the spreading top of a plume. Heat flows from a hot body to a cooler body. This is not a function of being above or below a reference point of depth.

So that the performance of the geothermal cell can be predicted, deep tests must be drilled. These holes must be of sufficient size to adequately determine the ability of the reservoir to produce fluids above 365° F at rates of more than 100,000 lbs. of steam per hour or 500,000 lbs. of liquid per hour. Although it is desirable that these fluids have less than 32,000 ppm dissolved solids and less than one (1) percent non-condensable gases in solution, they may be extremely corrosive and dangerous to test.

To determine if a commercial development is possible, three or four wells must test the reservoir to obtain the basic reservoir engineering data on producibility rates that are necessary. Reservoir pressure drawdown and buildup analysis must be conducted to determine reservoir permeability and extent. Fluid characteristics and analysis of non-condensibles present require extensive flow tests. Injectivity testing is required to develop plans for disposal and pressure maintenance systems. Rocks may produce fluids easily, but may not accept them on return to the reservoir. This must be established in the laboratory and confirmed in the field.

A review of the costs associated with finding, developing, and producing geothermal energy must consider that the actual dollar amounts reported are for a specific time and place. The following costs will be different than the amounts reported by each of the United Nations' symposia. This illustrates that changes in the required money are still being experienced in dry steam, high temperature flash, and moderate temperature flash or binary systems. The costs to find geothermal systems continue to increase as geologists learn there are cold holes very near hot areas; there are hot areas within an overall cold area; there can be a steam zone within a hydrothermal area; and there can be two different types of geothermal systems, vapor and liquid dominated, vertically separated within the same geographic area.

Development wells in the depth range of 5,000' to 10,000' are being drilled and completed for \$500,000 - \$1,500,000. Injection wells are being completed in the same cost range. The ratio of producers to injectors depends upon reservoir characteristics. The ratio will be between 1:1 or 1:2 for hot water systems. Water-steam lines from the producing wells to the generating plant can be estimated to cost \$35 to \$100/KW capacity. This cost is dependent upon the volume of fluid per kwh, the development pattern, and the plant location in relation to the producing wells. The amount of surface area used should be the minimum possible to achieve the maximum economic recovery. The engineering design work determines the most economical layout.

Techniques developed to drill slanted holes from a central platform can be used in developing geothermal reservoirs that have a broad area of heat with a local area of intense heat and where injection is feasible. Slant drilling is more costly than vertical drilling. Production pipelines are reduced in length if the plant is located adjacent to the producing islands. This results in a more efficient operation. The geology and geometry of the reservoir determines feasibility of using this method.

Condensate return, pipelines' design, and cost depend upon the uses for the condensate. If the condensate is mixed with the brine that is not flashed, a mixture similar to the produced fluids can be returned to the injection sites and return lines will be similar in size and cost as the production lines. If the condensate is used in the cooling system and allowed to evaporate, a small diameter pipeline can be used to return cooled water to injection lines. If this is so, the condensate pipeline can cost as little as \$4-\$15 per KW.

Plants built to use steam produced directly from a dry steam reservoir are the lowest in cost to build. PG&E's plant #15 is expected to cost \$320/KW with provisions for H_2S treatment. This is an increase of 250% over the average of the 1961-1974 period. In the same period, the cost of electricity generated averaged about 5.6 mills per net kilowatt hour. 1979 costs will have increased the price of electricity to 25 to 30 mills per kilowatt hour from steam fields.

Hot water flash plants have an extremely broad range of cost. This is because the temperature and chemical characteristics of the produced fluids and unit size have a wide range. This creates costs from \$400 per kilowatt to as much as \$700 per kilowatt. Double flash 45 net MW operating on low solids fluids at temperatures around 450° F most likely can be constructed for \$450 to \$475 per net kilowatt. Fluids 100° F cooler will require plants costing \$100 more per kilowatt capacity.

Binary units designed for using low bioling point fluids to drive the turbine are experimental designs. No plant greater than 5 MW has been operated so cost criteria are tenuous. Present estimates for approximately 50 MW plants range from Ben Holt Engineering's estimate of $500 per kilowatt to Ford Bacon & Davis shell and tube system at $655/kwh. A small 10 MW binary system is being constructed by Imperial Magma. This has a reported cost of $1,000 per KW.

A summary of estimated development costs after exploration expenses for the field supply, power plant, and ancillary equipment for a 50 megawatt hot water flash unit is as follows:

Table II

Development Wells (12)	$ 10,800,000
Injection Wells (6)	5,400,000
Pipelines	2,800,000
Miscellaneous Field Expense (includes interest & working capital)	9,000,000
Power Plant	25,000,000
TOTAL	$ 53,000,000

ECONOMIC CONSIDERATIONS

To obtain a comparison of geothermal fuels with the more widely used fuels is quite difficult, because each geothermal area requires a plant design specifically useful for that local area. The California Geyser's steam price of 16.5 mills per kwh is as inexpensive as geothermal energy can be produced in the U.S. today. This is a dry steam fuel, and the operators have more than a decade of experience in drilling, completions, and production operations. Optimum techniques have been developed so that maximum steam production per dollar invested can be maintained. The high energy content of this fluid provides a competitive heat rate, easy to construct collection systems, and the most simple of plant and reinjection facilities. The actual cost of the wells are frequently as high as $750,000 - $1,000,000, but the operation and the high utility of the steam allows a minimal price for the energy.

The wide variation of estimates of fuel costs and electricity generating costs derives from treatment of fuel processing and storage expense, income taxes, ad valorem taxes, insurance, interest during construction, return on investment required, and specific requirements for plants in the area of operation for the estimating companies. The utility usually expects to earn a minimum of 20% ROI on its equity portion. The exploration and producing investors have learned that a minimum acceptable rate of return on investment for their portion of the projects is also 20% ROI. The average conventional energy venture (non-geothermal) usually obtains about twice this rate of return.

The return on investment for the developer is most sensitive to the price received for the energy. Next to reliability of supply, the utilities desire to use geothermal energy in its electricity generating systems is dependent upon its price being low enough to make its use worthwhile. Much like coal and uranium, geothermal fuel prices will be a negotiated price between the supplier and the user. Each field will have significant differences in design so a uniform price cannot be expected for construction of the production facilities, or construction of the utilities conversion plant.

The nature of the reservoir geometry and the ability of the reservoir to respond to changes in production, rates, and temperatures, will determine the final costs for producing electricity from each geothermal project.

The basic structure of price must provide an attractive rate of return to the prospector. To achieve this, the prospector's risk capital investment and time at risk before income must be minimized. Most important, the revenue should reflect the actual value of the energy sold.

COST COMPARISONS

The cost comparisons between the various sources of energy that will be available and useable for electricity generation during the next decade will affect the rate of geothermal energy's growth. The economic desirability of the production or use of a fuel is sensitive to its price. Regulatory requirements have direct effect upon production and construction costs. The tax treatment for each fuel system is a dynamic one. This makes it very difficult to assess the resulting economics.

The amount of money needed to construct and operate plants to use each fuel is a strong component of how much the customer will pay per unit of fuel. The heat rate of the energy conversion system determines the amount of fuel needed to supply the plant. In electricity generating plants, the heat rate is the number of BTU's required to produce a net kilowatt hour. The average coal and oil burning plant uses 8,500 to 10,500 BTU/kwh. A nuclear plant uses about 14,000 BTU/kwh. Geothermal plants use between 21,000 to 33,000 BTU per net kwh.

OIL

Electricity produced from oil fired plants is directly related to the cost of low sulfur fuel oil. An oil fired turbine generator plant costs between $385.00 and $400.00 per kw. A combined cycle plant is about $300.00 per kw. The difference in heat factor, operating cost, and available capital for these plants establish which will be used for meeting the increased demand and plant replacement schedule within a utilities service area. The estimated cost of fuel oil in mills per kwh developed by Stanford Research Institute, is approximately 23 mills per kwh. Strong competition between suppliers results in a stabilizing effect upon the overall price of oil. Utility planners have estimated the range of price of oil to be 20.5 to 21 mills per kwh. These cost ranges combined with new plant costs will produce electricity between 33 and 44 mills per kwh.

COAL

Coal prices are related to specific sources of supply and dedication of specific sources of coal to certain plants. Coal does not presently have the wide range of usefulness that oil enjoys today. This limits the substitution of one coal for another.

The price of steam coal and plant construction costs to meet environmental requirements result in an estimated price of 35 mills for electricity generated in new coal plants. Fuel suppliers currently estimate coal can be delivered within a one-thousand mile radius for 9 to 10 mills per kwh if surface mining methods are used.

NUCLEAR

Nuclear fuel plants appear to offer the least expensive electricity for a non-indigenous source of energy.

The utility industry estimates they will be paying 6 to 6.5 mills per kwh for nuclear fuels and plant costs in 1977 dollars will be $800 to $1000 per KW. The estimated cost of electricity from such plants will be between 32 to 34 mills per KWH.

GEOTHERMAL

Comparison of conventional electricity prices with geothermal steam, electricity prices are a matter of public record. This is the least expensive of all thermal systems employed in the U.S. To obtain a comparison of hot water flash steam plants, it is necessary to use developments outside of the USA for performance factors. Economics of hot water flash to steam projects continue to be impressive. Cerro Prieto's development is very encouraging as exploratory work confirms this development can exceed 500 MW. The improvement in heat recovery with double flash units would reduce the cost of electricity and increase the size of reserves significantly. Seventy-five megawatts have now been developed and work is underway for the next 75 MW. The first unit of 75 MW was developed for $264/KW, and produced electricity for approximately $.008 tax free. Today, costs would be about twice that amount. The generation cost includes the well field operation as this is an integrated operation. It is estimated the second 75 MW plant will produce electricity for about 16 mills tax free.

It is possible to use the development work now in progress at Momotombo Nicaragua to evaluate the costs of developing a hot-water-flash-field today. DeGolyer McNaughton, the international consulting firm and Herman Dykstra, a reservoir engineering consultant, have completed examination of all the field test data from Momotombo. Tests using bottom hole pressure devices in selected wells were combined with full field flowing tests. The firm concluded that double flash turbines could produce 96 MW for more than 30 years using the portion of the reservoir developed. Subsequent completion tests have demonstrated more than 100 MW capacity.

Turbine specifications are now being prepared to have 8 plant turbine with 80 psig first stage and 20 psig second stage. The power plant for this 225° C field may have two 35 MW units in operation by mid 1980. The estimated cost for the electricity generating plant installed will be $460/KW. A savings of $26 million in foreign exchange would result from this development.

STEAM

Geyser's steam price of 16.5 mills per kwh is about as inexpensive as geothermal energy can be produced today. The 1978 price of 16.5 mills per kwh is well below the competitive value of this energy. 20 mills per kwh would be a price more nearly reflecting its actual value in an area using oil or coal for electricity generation.

Plants to use a dry steam are the lowest in cost to build. PG&E's plant #15 is expected to cost $320/KW with provisions for H_2S treatment. This is an increase of 250% over the average of the 1961-1974 period. In the same period, the cost of electricity generated averaged about 5.6 mills per net kilowatt hour. 1979 operating costs will have increased the price of electricity to 25 to 30 mills per kilowatt hour.

Summarizing the preceding discussion on comparison of costs and resultant prices of electricity, we can tabulate oil, coal, nuclear vs. geothermal as follows:

	Oil	Coal	Nuclear
Fuel mills per kwh	20-23	9-11	6-7
Plant $/KW	300-400	580-950	800-1000
Electricity Busbar mills/kwh	33-44	35-36	32-34

	Geothermal		
	Steam	Flash 450° F	Binary
Fuel mills per kwh	14.5-16	16-20	26-30
Plant $/KW	320	450-475	500-1000
Electricity Busbar mills/kwh	22.5-24	25-30	40-48

RESERVE ESTIMATES

With these competitive conditions and an idea of the required investments in plant and fields, we can now estimate the potential reserves identified in relation to the proven reserve.

The proven reserves of the Geysers is now 908 megawatts. The potential reserves are another 1100 MW. To infer that the hot water area surrounding the dry steam reservoir will be productive of waters that will be used in flash steam plants is reasonable. Inferred hot water flash reserve should be approximately 1,000 MW.

The proven reserves in the Imperial Valley are 400 megawatts. Potential reserves of Brawley, East Mesa, Heber, Niland, and Westmoreland total 1600 MW. Reserves have been inferred with another 1,000 MW in these and similar anomalies within the province. Considerable work must be done on conversion systems, and deep drilling in the California portion of the Imperial Valley if another 5,000 MW are to be moved from the resource category into the reserve category in the next 20 years.

Coso, Lassen, Mono-Long Valley, Mammoth, Randsburg, can be credited with about 700 MW of inferred reserves. Sufficient drilling has not been done in these areas to estimate reservoir quality, water characteristics, and temperature distribution.

In the western Utah area, Roosevelt is the only area with proven reserves. It appears that sufficient testing and plant design work has been completed to assign 80 MW to that classification. 120 MW potential and 300 MW inferred reserves can be assigned to Roosevelt on information now available. The remainder of that general area including Cove Fort - Sulfurdale, Thermal-Black Mountain should have 1,000 megawatts potential reserves and 500 MW inferred.

Testing of potential areas in Nevada has not progressed to the stage where proven reserves can be assigned. The potential reserves of Phillips' three areas, and Chevrons' two areas in the northern half of the state, indicates 400 MW reserve. An additional 600 MW can be inferred on the basis of drilling data being extrapolated with geophysical surveys. With continued confirmation success in the Carson sink area, an additional 500 MW could be moved from resource to inferred reserves. New Mexico's Valles Caldera is considered as having 100 MW potential reserve. From the size of the anomaly and the temperature indicated by surface springs, an inferred reserve of another 300 MW should be assigned. This area has a total reserve of 400 MW.

Oregon does not have proven reserves except in the direct use of the heat contained in the subsurface waters around Klamath Falls. The exploration for geothermal energy useful for generation of electricity has been encouraging in the northeast extension of the Gerlach-Baltazor trend into Oregon from northwest Nevada. The Alvord area has 200 MW potential reserves and 100 MW inferred. Between Alvord and Vale Hot Springs another 400 MW can be inferred. An additional 300 MW can be inferred from other heat flow and geophysical survey work in the general area.

This table summarizes these reserve catagories.

Eastern S.N. Plain
Rio Grande Rift

SUMMARY

ELECTRICITY GENERATION RESERVES

	Proven (Measured) MW	Potential (Indicated) MW	Inferred (Geol-Geoph) MW
Geysers	908	1,100	1,000
Imperial Valley	400	1,600	1,000
Coso-Lassen, Long-Valley, Mammoth, Randsburg			700
Roosevelt	80	120	300
Cove Fort, Sulferdale, Black Mountain-Thermal		1,000	500
N. Nevada		400	600
New Mexico		100	300
Alvord Area		200	100
Alvord to Vale			400
Other Oregon SE			300
Subtotal	1,388	4,500	5,200
Total Reserves	11,188 MW		

The direct use of geothermal heat in the U.S. is on a local project basis except in Klamath Falls, Oregon and Boise, Idaho. Local greenhouse operations, individual processing plants in industrial and agricultural projects are found throughout the western U.S., Alaska, Texas and Southeast Appalachians. It is estimated these present direct uses represent proven reserves of 35 MW.

Reserves cannot be assigned to geopressure-geothermal projects. It is hoped the government research work in progress can develop sufficient data to provide inferred reserves in 20 years.

Reserves now identified in the three catagories total 11,088 MW. This rapid build up from the reserve of 500 MW existing just four years ago demonstrates an aggressive search for and investment in producing areas. The 164,000,000 barrels of fuel oil that will be saved annually for electricity generation when this is developed is about 1/10 the amount of direct use potential existing today.

An oil accummulation to provide 164,000,000 bbls per year for 30 years would require 4.9 billion bbls to be available for production. Consider that less than .2 of 1% of all wildcats drilled in the U.S. during the last four years discovered producible reserves over the life of the field greater than 1 mm bbls of oil.

To assess the impact of the development of this reserve now identified plus the stimulus such development will give to exploration requires an assumption that the governmental agencies believe indigenous sources of energy are necessary to the economy of the USA.

In 1975 the forecast of the growth of geothermal capacity spanned 5,000 MW to 20,000 MW on line by 1985. The forecast by B. Greider at the 1975 United Nations Symposium was that 6,000 MW capacity would be on line by 1985. This required a reserve of 11,000 megawatts be discovered. The reserve has been discovered. The majority of the prospects contributing to this growth were on federal lands. These same prospects were recognized to be primarily in a temperature range that during most of the productive lifetime the reservoir would produce fluids at less than 400° F. The basic assumption underlying these forecasts was that viable economic incentives for geothermal would be similar to ones for other natural resource developments.

Stanford Research Institute, The University of California, Riverside, and Science Application Inc. have each provided thoughtful studies on the effect of tax incentives for the development of geothermal resources. The effect of such tax treatment has been focused on the resulting price of electricity or upon how much income this would "shelter" for the producer.

Each study has sidestepped the critical question of how large a capacity can be economically developed from recognized prospects with the subject incentives. How many would be developed lacking such economic stimuli. The next question that should have been answered is: what is the flow back to government agencies in tax revenues if certain incentives are initiated? This demands careful analysis of the possibility of reduced tax flow from projects that are certain to be developed without the incentives versus the increased tax revenue from those projects that would not have been developed without the incentives.

Consideration of the dynamic effect of taxation regulations on an incipient industry will show a tremendous benefit to government agencies in increased tax revenues. Robert Rex prepared the following two illustrations demonstrating the flow of monies to federal, state, and county agencies for a single 48 net MW project on federal lands and the effect if 1,000 MW developed on federal leases.

ESTIMATED GOVERNMENT REVENUES FROM FIELD DEVELOPMENT PROGRAM

1000 MW PROJECT

10% Federal Royalty Payments	$1,462,500,000
Federal Income Taxes	1,243,750,000
State Income Taxes	1,398,125,000
Ad Valorem Taxes	345,625,000
	$4,450,000,000

ASSUMES:
25 MILS/KWH
30 YEAR PROJECT LIFE
6% ANNUAL INFLATION RATE

ESTIMATED GOVERNMENT REVENUES FROM FIELD DEVELOPMENT PROGRAM

EAST MESA 48 MW PROJECT

10% Federal Royalty Payments	$ 70,200,000
Federal Income Taxes	67,110,000
State Income Taxes	16,590,000
Ad Valorem Taxes	59,700,000
	$ 213,600,000

ASSUMES
25 MILS/KWH
30 YEAR PROJECT LIFE
6% ANNUAL INFLATION RATE

If the reserves now known on federal lands are developed additional ones will be added in the process of development and by the increased exploration attracted to the area of successful development. Five thousand megawatts production on federal lands and two thousand MW on non-federal lands should return to the government 903 million dollars in revenues each year over the first 30 years of the projects lives. 7.02 billion dollars would flow to the federal government as royalty, 9.4 billion as income tax. 2.3 billion would be allocated to the various states' income tax revenues and more than 8.4 billion dollars to local county governments as ad valorum taxes.

SUMMARY

In 1973 the geothermal reserves in the U.S. were 500 MW. Reserves identified since 1970 total about 11,100 MW. This is enough energy to supply the total electrical needs for 11,000,000 people. To generate the same electricity using fuel oil 164 million barrels per year would be needed. Five billion barrels of oil would need to be discovered to supply the equivalent energy for 30 years.

Geothermal energy can compete with the other types of energy now being used in the U.S. To do so, the energy must be available from its reservoir at a temperature above 400° F. Below this temperature, operating cost rise significantly as the number of wells to produce and reinject the fluid increases.

Tax incentives must be provided to encourage significant investment in the mid temperature hot water resources if this type of energy is to be developed.

The cost of the plants rise rapidly as the temperature of the reservoir decreases. The volume of fluid required to move through the system increases rapidly to supply the required heat. There are economic limits established by temperature that must be recognized. If the BTU content of a ton of coal drops, there is a point where it is not useable for power production. The same is true for oil and gas fluids as their associated water or inert gas ratio increases. Geothermal fluids quality and usefulness is also dependent upon its BTU content per unit volume produced. The building of power plants for mid temperature projects is critical to the utilization of this large resource.

For this reason, it is difficult to present a specific cost of electricity produced by broad types of resource. The probable range of prices for electricity generated from steam and hot water reservoirs today is:

	Mills/KWH
Steam 450° F and above	22.5 - 24
Hot water flash - below 400° F	36 - 50
above 400° F	25 - 30
Binary	40 - 48

The expected value of a geothermal project, the field costs and the resulting costs to generate electricity are affected by the interrelated variables such as:

- Temperature of fluids
- Composition of fluids
- Geology of reservoir
- Cost drilling
- Flow rate per well
- Well spacing
- Turbine system
- Operating costs.

Research must continue on how to make fluids with temperatures below 400° F useful. The technology is now mature. There are vast quantities of heat in this resource awaiting the solution to the economic problems of using this low grade heat.

Risk capital must be readily available in units of 10 to 15 million dollars at the beginning of exploration. Development to 400 MW may require up to 100 million dollars investment before payout of the first 50 MW unit is obtained. The investor with sufficient money to carry out a successful program will compare the return of invested capital offered by similar projects (utilizing similar technology and business know-how). The projects offering the best rate of return for similar risk and investment will usually be the ones selected for funding.

The biggest problem in obtaining risk capital is the uncertainty of the business. This includes the discrimination in tax treatment of hot water versus steam. This precludes being able to market the energy at competitive prices and obtain as favorable rate of return as other industries offer. Prospective investors should have assurance that government rules and regulations will encourage the discovery and use of this energy.

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APPENDIX

GEOPRESSURE - GEOTHERMAL RESERVOIRS

Tertiary basins around the world have been discovered to have reservoirs at greater than normal pressure gradients. These geopressured zones frequently have higher than normal geothermal gradients. Exploration and field development for oil and gas production in Texas and Louisiana has outlined an area of interest extending several hundred miles from the Rio Grande River to the Delta of the Mississippi parallel to the Gulf Coast. I have not recognized any reserves in this catagory.

The economics of developing this combination of kinetic energy, low grade heat energy, and methane, is unfavorable at this time. Uncertainty as to the producibility is caused by the knowledge that to have geopressure, the sand formations must be discontinuous and the reservoirs must be confined in a limited areal configuration. Without such limits, normal temperatures and pressures would exist. In the deeper reservoirs of the geopressured areas, higher temperatures have been reported by Louisiana State University personnel. These deeper reservoirs (18,000' to 19,000') are reported to be at temperatures above 400°F. The low permeabilities reported with the moderate reservoir thickness (400') will require a maximum producing rate of 20,000 bbls per day (instead of the 40,000 bbls usually used) per well if excessive drawdown is to be avoided. The wells would probably require 640 acre spacing to eliminate well interference effects. The producer-injector ratio should be planned for 1:1. However, an initial testing period for the first modules can confirm this assumption.

The Department of Energy plans a deep $6,000,000 well test of this type of geopressured prospect. The results will be valuable in trying to design a workable method to recover and use this very expensive submarginal energy accumulation. Tables III, IV, and V, synthesize my opinions.

Table III

GEOPRESSURE ECONOMICS

BASIS

Reservoir Thickness (assumed)	400'
Permeability/Ft.	Less than 10 md
Surface Pressure (desired)	3,000 PSI - 4,000 PSI
Flow Before Injection req'd	1.0 - 1.1 billion bbls
Time Before Injection	Less than 2 years
Minimum spacing producers (interference)	640 acres
Draw Down Limit	3500 PSI
Injection Pressure	5000 PSI
Net Methane in Solution	75 SCF/bbl

Table IV

GEOTHERMAL ECONOMICS

SCOPE FACILITIES

Field Size	200 MW
Barrels Per Year	600 Million
Barrels Per Day Per WL l1	20,500
10 Wells Each	25 MW Unit
80 Producers	80 Injectors
Plant Net	200 x .85
Plant Load Factor	70%

Operating costs and taxes can only be estimated. It is certain they will not be less than those experienced in keeping a gas or oil field in operating for 30 years.

Table V

INVESTMENT & REVENUE

160 Wells @ $6 M̄ Eac. (includes surface facilities)		$960 M̄
Heat @ .020/kwh	Gas @	$ 1.75 M̄CF
Energy Revenue		21.25 M̄/Yr
Gas Revenue		85.75 M̄/Yr
Revenue Total		$107.00 M̄/Yr.

EXPENSE

Operating Costs $200/Well/Day	= $12 M̄/Yr
Property & State Tax 15% x Gross/Yr	= 16 M̄
Total Expense	= $28 M̄

INCOME

Income - $107M̄ - $28M)	= $79 M̄
Net $79M x 50% (Income Taxes)	= $39.5 M̄
Payout $960/$39.5 = 24 Years	ROI = 4%

There are adequate problems to solve in utilization of geopressured-geothermal reservoirs. These are primarily related to geologic problems. Discontinuous sands form the reservoir rocks in geopressured systems. The lack of continuity prevents fluid moving to lower pressured zones in a natural adjustment to normal pressure results in the abnormal geopressures. This very discontinuity results in limited reservoirs of restricted areal extent.

In many geologic situations, faulting and fracturing provide the plumbing that allows geothermal fluids to move into the producing reservoirs. The vertical movement of fluids along these faults is thought to be an important factor necessary for high production rates over the long life required for energy production.

Geopressured reservoirs have no such plumbing, otherwise, their pressures would be normal. The sealed faults in the geopressured areas will cause rapid pressure decline unless produced volumes are compensated by having equal volumes reinjected into the same sand bodies. It is for this reason this source of energy must remain an energy resource with no defined reserves.

Item 7

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GEOTHERMAL POTENTIAL 1978

B. Greider
Vice President IEC
May 17, 1978

Interest in using the heat of the earth to provide an indigenous source of energy has begun to increase almost as rapidly as energy bills in the United States. Natural resource development companies and groups of investors are increasing their exploration for accumulations of heat that can be used in electrical generation, space heating and cooling, agriculture, and industrial process heating.

Developers expect the natural sources of heat above 450° F in the western United States to produce electricity at prices competitive with low sulfur coals shipped from the Powder River basin of Wyoming to the electricity generating centers supplying western Nevada and California. Water within the low energy 150° F temperature range can provide processing heat, if the source is in a location where the energy can be used in the U.S. It is expected that sulfur limits for fuel oil will be set similar to coal. To meet such standards, additional investment and costs will be required to prepare acceptable fuel. With such increases in cost, new uses for geothermal heat (energy) will become practical. When that happens, more people will become interested in joining the exploration search to find and develop new deposits of heat for production of energy.

The development of a geothermal reservoir is capital-intensive, requires expert planning, and long times from initial expenditure until positive income is achieved. The utilization of a developed project requires extensive engineering, approximately two years in negotiation with governmental agencies, and a lot of money.

The costs of maintaining and operating the producing fields is about four to five times greater than the capital investment. An important portion of this cost is associated with the injection system that collects the water after the heat is removed and then returns it to the subsurface reservoirs. Reducing these costs is an essential objective if geothermal is to be competitive with other fuels.

Countries with high fuel costs and geothermal sites are now developing a wide variety of geothermal plants. Japan appears to be building the most efficient flash systems for use in hydrothermal areas rimming the Pacific Ocean.

The assessment of geothermal energy resources by considering this energy to simply be the heat of the earth provides estimates of gigantic size. Useful geothermal reserve assessment requires professional analysis. The goal is to determine how much heat can be produced at a useful rate and temperature for at least twenty years from one area. This demands a

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Dear Stan:
Most of this is old hat to you. This is the basic format of the presentation I made at the GRC short course for the Wash. D.C. workers
Regards Bob.

thorough understanding of the manner in which heat is transported to areas of accumulation, how it accumulates, the methods and costs to find, produce, and convert to a useable form of energy. With those studies in hand, a person can then determine what part of this resources can be sold in competition with other fuels and thereby establish the size of the reserve.

Accessments of the supply of geothermal energy have been published by government agencies, private companies, universities and inter-governmental agencies such as the United Nations. These estimated supplies have been prepared in megawatts per year, joules per year, giga watt centuries, giga calorie centuries, per cent of the national energy budget, the equivalent bbl(s) of oil, and per cent electricity generated per year.

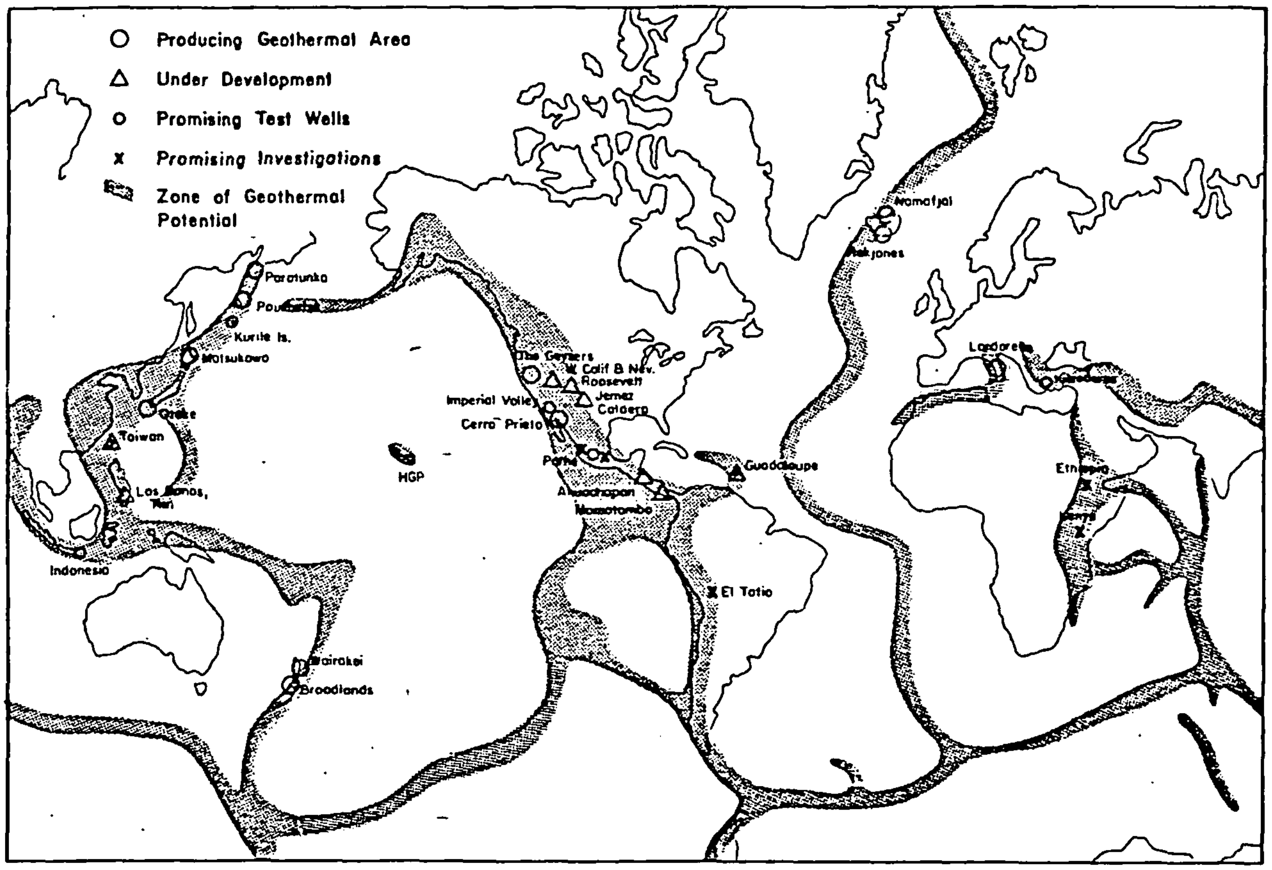
The supply has been related to all the heat present above an arbitrary temperature datum, the amount of heat between certain temperature levels, that heat contained in producing water, and that heat contained in the rock framerock transferred to the moving body of water, and the amount that could be produced if the government would provide various incentives.

These incentives have included tax credits, deductions in tax calculations, investment tax credits, rapid depreciation, and extensive depletion allowances. Other incentives include aid in exploration, aid in developing, engineering of generating plants, financing of generating plants, and reservoir engineering studies. Very little has been prepared showing the increased benefit to governmental programs, including tax revenue by demonstrating the increased flow of dollars from projects that would become profitable with this aid compared to project tax revenues that would be commercial without this aid.

The actual potential of geothermal energy is affected by how the resource and reserves are calculated. These calculations must consider availability and application of the governmental incentives, the price of other energy sources, versus the market price of geothermal energy, and the reliability of the production forecast. The size of required investment, and the expected profit generated by those investments, plus the availability of lands to explore will be the motivating forces in determining the true potential of geothermal energy development in the United States.

The most important factor in converting any resource into a reserve is how the individuals that are actively dedicated to discovery and development, attack the problem. The key to successful reserve development is the quality of the people assigned to the task.

A casual examination of geothermal areas of the world, shown in figure 1, will allow even the uniniated to estimate the supply of geothermal energy that is presently useful in the generation of electricity. The world's total geothermal generating capacity in development and developing projects with significant reservoir testing, is approximately 2,600 megawatts. The potential areas identified by preliminary investigation of sufficient extent to allow analogies with development areas is estimated to have an additional 12,000 megawatts of indicated reserves. Inferred reserves of an additional 20,000 megawatts of electricity capacity may be developed within the next 20 years. The existence of geothermal energy does not assure the resource will be converted to a reserve. In a free economy the competition in the market place and the return on the potential investment will determine if and when these resources will become useful.



GEOTHERMAL POWER DEVELOPMENT
MAP 1

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The United States has the greatest producing capacity in the world at this time. The Geysers in northern California produces and has more capacity building than any other commercial producing geothermal country in the world. Those areas capable of commercial production or that have commercial plants under engineering design are listed in Table I.

Table I

World Geothermal Generating Capacity

In Megawatts

Country	Area	Operating Capacity	Engineering & Construction
U. S. A.	The Geysers	502	450
	Roosevelt	- -	80
	Heber	- -	110
	E. Mesa	- -	60
	Other	- -	200
Italy	Larderello	385	
	Travale	15	
	Mt. Amiato	22	
New Zealand	Wairakei	150	
	Broadlands		165
	Kawerau	10	
Japan	Matsukawa	20	
	Otake	13	55
	Onuma	10	
	Oninobe	25	
	Hatchobaru		55
	Takinow		55
Mexico	Cerro Prieto	75	75
	Pathe	3.5	
El Salvador	Ahuachapan	35	60
Nicaragua	Momotombo		30
Iceland	Namafjell	2.5	
	Krafla		55

must be sufficient horizontal and vertical permeability to allow the fluid to move easily. A 6,000 ft. to 8,000 ft. well must sustain flow rates of more than 100,000 lbs. of steam per hour, or 500,000 lbs. of water (above 325° F) per hour for 20 to 25 years to be considered commercial for electricity generation. Direct use of heat for industrial heating or space heating and cooling does not require such high heat output. The lower temperatures for such uses can be found in a greater number of anomalies, however, their usefulness is dependent upon low costs being achieved in development and production.

The geologic model that is generally accepted by geothermal explorers and developers (Figure 2) has three basic requirements to function:

1. A heat source (presumed to be an intrusive body) that is above 1200° C and within 16 Km of the surface.
2. Meteoric waters circulating to depths of 10,000 ft. - 20,000 ft. where heat is transferred from the conducting impermeable rocks above the heat source.
3. Vertical permeability above the heat source connecting the conducting rocks with a porous permeable reservoir that has a low conductivity impermeable heat retaining member at its top.

Water, expanding upon being heated, moves buoyantly upward in a hot concentrated plume. Cold waters move downward and inward from the basin's margins to continue the heat transfer process. Heat is transported by convection in this part of the model.

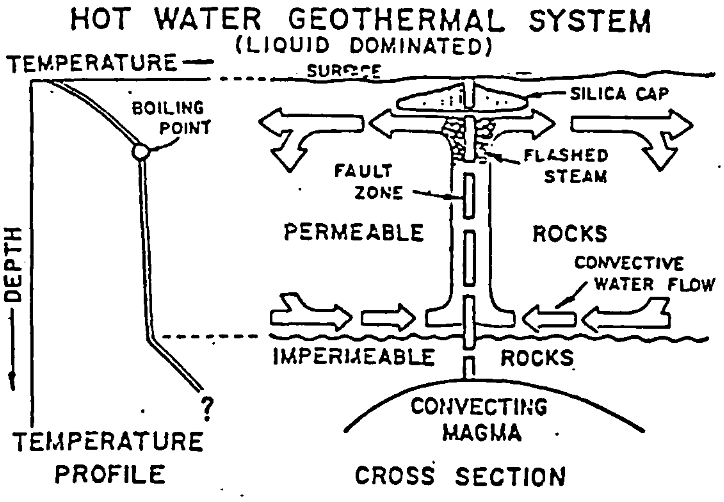

Fig. 2 — Geological Model of a Hot Water Geothermal System (after White, 1973).

Geologic investigation is the necessary ingredient that makes all other techniques useful. Broad reconnaissance of the surface data integrated into subsurface data is used to find an area of general interest. The ingenuity of the prospect finder in using data available to all workers determines whether an exploration program moves into advanced stages of using the proper combinations of the above methods. Geologic interpretation of the data acquired may justify the money required for exploratory drilling. The results of the drilling must be integrated into the geologic investigation to determine if a promising prospect is present.

The investigation must establish that:

1. High heat flow or strong temperature gradients are present at depth.

2. The geology provides reasonable expectation that a reservoir sequence of rocks is present at moderate depths from 2000' to 6000'.

3. The sequence of rocks offers easy drilling with minimal hole problems.

4. A high base temperature and low salinity waters as indicated by geochemistry of water sources should be present. The surface alteration and occurrence of high heat flow should cover an area large enough to offer the chance for a field capacity of more than 200 MW.

Interpretation of geochemical data requires professional skill in geology and chemistry. If the geology is well known, useful information can be developed.

Geophysical surveys are useful in predicting the general area and depth of high temperature rocks and water. Rocks at depth are better conductors of electricity (natural and induced currents) when there is an increase in temperature, an increase in porosity, an increase in clay minerals, or an increase in salinity in their contained fluids.

Table I from C. Heinzelman's presentation of October 15, 1977, illustrates exploration techniques and associated costs. The overall amount of money (per successful prospect) required is 2.5 million to 4.75 million 1977 dollars. This provides for limited failure and follow up costs, but does not include the other exploration failures and land costs.

Table I

EXPLORATION TECHNIQUES & APPROXIMATE COSTS

Objective	Technique	Approximate Cost ($)
Heat Source & Plumbing	Geology	$ 15,000
	Microseismicity	15,000
Temperature Regime	Gravity	20,000
	Resistivity	25,000
	Tellurics & sagnetotellurics	40,000
	Magnetics	15,000
	Geochemistry (Hydrology)	12,000
	Temperature Gradient 20 holes	100,000
	Stratigraphic Holes (4)	160,000- 240,000
Reservoir Characteristics	Exploratory wells (3)	1,800,000-4,000,000
	Reservoir test	250,000
Total to Establish a Discovery		$2,472,000-4,752,000

This is probably the minimum expenditure to move a portion of the resource into a reserve.

Upon deciding that a significant geothermal anomaly exists, the rate of engineering expenditures must increase rapidly to determine whether the development can proceed. Essentially, there are no set figures for what it costs to develop a geothermal field. The basic reason for this is that each depends upon engineering the development to be compatible with the geology of the accumulation, and the requirements of the electricity generating system. The electricity generating system must be designed within the constraints of available temperature, rate of production, and ambient conditions of the field site. The key variables are:

1. Temperature of the fluids produced.
2. Composition of the reservoir fluids.
3. Composition of surface or near surface fluids.
4. Geology of the reservoir framework.
5. Flow rates that can be sustained by the reservoir.
6. Cost of drilling in the prospect area.
7. Well spacing and geometry of the producing and injection sites.
8. Turbine system to be used.
9. General operating costs in the area.

Test Wells - Thermal evaluation requires the drilling of test holes. Heat flow and temperature gradient evaluation requires drilling to intermediate depths. Confirmation drilling requires holes drilled to the actual reservoir for diagnostic evaluation.

Heat flow and temperature gradients measured in the upper 100 to 500 ft. depth are useful in describing the area where the heat transfer is most intense. When mapped, these do give a qualitative analysis as to the location and shape of the hottest near-surface heat accumulation. Linear projection of temperatures obtained near the surface cannot be used to predict the temperatures that will be encountered 2000-3000 ft. below the surface, even if the section below has a uniform lithology and the geothermal graident is a straight slope. The temperature for a fluid-saturated system cannot be projected to a maximum above that for boiling water at the pressure calculated for the depth of projection. At some point along the boiling point curve, the temperature of the system may become isothermal and the rocks and fluids will have the same temperature for many hundreds of feet deeper. The rock temperature may decrease as a hole is drilled deeper if the hole is on the descending edge of a plume of hot water or merely below the spreading top of a plume. Heat flows from a hot body to a cooler body. This is not a function of being above or below a reference point of depth.

So that the performance of the geothermal cell can be predicted, deep tests must be drilled. These holes must be of sufficient size to adequately determine the ability of the reservoir to produce fluids above 365° F at rates of more than 100,000 lbs. of steam per hour or 500,000 lbs. of liquid per hour. Although it is desirable that these fluids have less than 32,000 ppm dissolved solids and less than one (1) percent non-condensable gases in solution, they may be extremely corrosive and dangerous to test.

To determine if a commercial development is possible, three or four wells must test the reservoir to obtain the basic reservoir engineering data on producibility rates that are necessary. Reservoir pressure drawdown and buildup analysis must be conducted to determine reservoir permeability and extent. Fluid characteristics and analysis of non-condensibles present require extensive flow tests. Injectivity testing is required to develop plans for disposal and pressure maintenance systems. Rocks may produce fluids easily, but may not accept them on return to the reservoir. This must be established in the laboratory and confirmed in the field.

A review of the costs associated with finding, developing, and producing geothermal energy must consider that the actual dollar amounts reported are for a specific time and place. The following costs will be different than the amounts reported by each of the United Nations' symposia. This illustrates that changes in the required money are still being experienced in dry steam, high temperature flash, and moderate temperature flash or binary systems. The costs to find geothermal systems continue to increase as geologists learn there are cold holes very near hot areas; there are hot areas within an overall cold area; there can be a steam zone within a hydrothermal area; and there can be two different types of geothermal systems, vapor and liquid dominated, vertically separated within the same geographic area.

Development wells in the depth range of 5,000' to 10,000' are being drilled and completed for \$500,000 - \$1,500,000. Injection wells are being completed in the same cost range. The ratio of producers to injectors depends upon reservoir characteristics. The ratio will be between 1:1 or 1:2 for hot water systems. Water-steam lines from the producing wells to the generating plant can be estimated to cost \$35 to \$100/KW capacity. This cost is dependent upon the volume of fluid per kwh, the development pattern, and the plant location in relation to the producing wells. The amount of surface area used should be the minimum possible to achieve the maximum economic recovery. The engineering design work determines the most economical layout.

Techniques developed to drill slanted holes from a central platform can be used in developing geothermal reservoirs that have a broad area of heat with a local area of intense heat and where injection is feasible. Slant drilling is more costly than vertical drilling. Production pipelines are reduced in length if the plant is located adjacent to the producing islands. This results in a more efficient operation. The geology and geometry of the reservoir determines feasibility of using this method.

Condensate return, pipelines' design, and cost depend upon the uses for the condensate. If the condensate is mixed with the brine that is not flashed, a mixture similar to the produced fluids can be returned to the injection sites and return lines will be similar in size and cost as the production lines. If the condensate is used in the cooling system and allowed to evaporate, a small diameter pipeline can be used to return cooled water to injection lines. If this is so, the condensate pipeline can cost as little as \$4-\$15 per KW.

Plants built to use steam produced directly from a dry steam reservoir are the lowest in cost to build. PG&E's plant #15 is expected to cost \$320/KW with provisions for H_2S treatment. This is an increase of 250% over the average of the 1961-1974 period. In the same period, the cost of electricity generated averaged about 5.6 mills per net kilowatt hour. 1979 costs will have increased the price of electricity to 25 to 30 mills per kilowatt hour from steam fields.

Hot water flash plants have an extremely broad range of cost. This is because the temperature and chemical characteristics of the produced fluids and unit size have a wide range. This creates costs from \$400 per kilowatt to as much as \$700 per kilowatt. Double flash 45 net MW operating on low solids fluids at temperatures around 450° F most likely can be constructed for \$450 to \$475 per net kilowatt. Fluids 100° F cooler will require plants costing \$100 more per kilowatt capacity.

Binary units designed for using low bioling point fluids to drive the turbine are experimental designs. No plant greater than 5 MW has been operated so cost criteria are tenuous. Present estimates for approximately 50 MW plants range from Ben Holt Engineering's estimate of $500 per kilowatt to Ford Bacon & Davis shell and tube system at $655/kwh. A small 10 MW binary system is being constructed by Imperial Magma. This has a reported cost of $1,000 per KW.

A summary of estimated development costs after exploration expenses for the field supply, power plant, and ancillary equipment for a 50 megawatt hot water flash unit is as follows:

Table II

Development Wells (12)	$ 10,800,000
Injection Wells (6)	5,400,000
Pipelines	2,800,000
Miscellaneous Field Expense (includes interest & working capital)	9,000,000
Power Plant	25,000,000
TOTAL	$ 53,000,000

ECONOMIC CONSIDERATIONS

To obtain a comparison of geothermal fuels with the more widely used fuels is quite difficult, because each geothermal area requires a plant design specifically useful for that local area. The California Geyser's steam price of 16.5 mills per kwh is as inexpensive as geothermal energy can be produced in the U.S. today. This is a dry steam fuel, and the operators have more than a decade of experience in drilling, completions, and production operations. Optimum techniques have been developed so that maximum steam production per dollar invested can be maintained. The high energy content of this fluid provides a competitive heat rate, easy to construct collection systems, and the most simple of plant and reinjection facilities. The actual cost of the wells are frequently as high as $750,000 - $1,000,000, but the operation and the high utility of the steam allows a minimal price for the energy.

The wide variation of estimates of fuel costs and electricity generating costs derives from treatment of fuel processing and storage expense, income taxes, ad valorem taxes, insurance, interest during construction, return on investment required, and specific requirements for plants in the area of operation for the estimating companies. The utility usually expects to earn a minimum of 20% ROI on its equity portion. The exploration and producing investors have learned that a minimum acceptable rate of return on investment for their portion of the projects is also 20% ROI. The average conventional energy venture (non-geothermal) usually obtains about twice this rate of return.

The return on investment for the developer is most sensitive to the price received for the energy. Next to reliability of supply, the utilities desire to use geothermal energy in its electricity generating systems is dependent upon its price being low enough to make its use worthwhile. Much like coal and uranium, geothermal fuel prices will be a negotiated price between the supplier and the user. Each field will have significant differences in design so a uniform price cannot be expected for construction of the production facilities, or construction of the utilities conversion plant.

The nature of the reservoir geometry and the ability of the reservoir to respond to changes in production, rates, and temperatures, will determine the final costs for producing electricity from each geothermal project.

The basic structure of price must provide an attractive rate of return to the prospector. To achieve this, the prospector's risk capital investment and time at risk before income must be minimized. Most important, the revenue should reflect the actual value of the energy sold.

COST COMPARISONS

The cost comparisons between the various sources of energy that will be available and useable for electricity generation during the next decade will affect the rate of geothermal energy's growth. The economic desirability of the production or use of a fuel is sensitive to its price. Regulatory requirements have direct effect upon production and construction costs. The tax treatment for each fuel system is a dynamic one. This makes it very difficult to assess the resulting economics.

The amount of money needed to construct and operate plants to use each fuel is a strong component of how much the customer will pay per unit of fuel. The heat rate of the energy conversion system determines the amount of fuel needed to supply the plant. In electricity generating plants, the heat rate is the number of BTU's required to produce a net kilowatt hour. The average coal and oil burning plant uses 8,500 to 10,500 BTU/kwh. A nuclear plant uses about 14,000 BTU/kwh. Geothermal plants use between 21,000 to 33,000 BTU per net kwh.

OIL

Electricity produced from oil fired plants is directly related to the cost of low sulfur fuel oil. An oil fired turbine generator plant costs between $385.00 and $400.00 per kw. A combined cycle plant is about $300.00 per kw. The difference in heat factor, operating cost, and available capital for these plants establish which will be used for meeting the increased demand and plant replacement schedule within a utilities service area. The estimated cost of fuel oil in mills per kwh developed by Stanford Research Institute, is approximately 23 mills per kwh. Strong competition between suppliers results in a stabilizing effect upon the overall price of oil. Utility planners have estimated the range of price of oil to be 20.5 to 21 mills per kwh. These cost ranges combined with new plant costs will produce electricity between 33 and 44 mills per kwh.

COAL

Coal prices are related to specific sources of supply and dedication of specific sources of coal to certain plants. Coal does not presently have the wide range of usefulness that oil enjoys today. This limits the substitution of one coal for another.

The price of steam coal and plant construction costs to meet environmental requirements result in an estimated price of 35 mills for electricity generated in new coal plants. Fuel suppliers currently estimate coal can be delivered within a one-thousand mile radius for 9 to 10 mills per kwh if surface mining methods are used.

NUCLEAR

Nuclear fuel plants appear to offer the least expensive electricity for a non-indigenous source of energy.

The utility industry estimates they will be paying 6 to 6.5 mills per kwh for nuclear fuels and plant costs in 1977 dollars will be $800 to $1000 per KW. The estimated cost of electricity from such plants will be between 32 to 34 mills per KWH.

GEOTHERMAL

Comparison of conventional electricity prices with geothermal steam, electricity prices are a matter of public record. This is the least expensive of all thermal systems employed in the U.S. To obtain a comparison of hot water flash steam plants, it is necessary to use developments outside of the USA for performance factors. Economics of hot water flash to steam projects continue to be impressive. Cerro Prieto's development is very encouraging as exploratory work confirms this development can exceed 500 MW. The improvement in heat recovery with double flash units would reduce the cost of electricity and increase the size of reserves significantly. Seventy-five megawatts have now been developed and work is underway for the next 75 MW. The first unit of 75 MW was developed for $264/KW, and produced electricity for approximately $.008 tax free. Today, costs would be about twice that amount. The generation cost includes the well field operation as this is an integrated operation. It is estimated the second 75 MW plant will produce electricity for about 16 mills tax free.

It is possible to use the development work now in progress at Momotombo Nicaragua to evaluate the costs of developing a hot-water-flash-field today. DeGolyer McNaughton, the international consulting firm and Herman Dykstra, a reservoir engineering consultant, have completed examination of all the field test data from Momotombo. Tests using bottom hole pressure devices in selected wells were combined with full field flowing tests. The firm concluded that double flash turbines could produce 96 MW for more than 30 years using the portion of the reservoir developed. Subsequent completion tests have demonstrated more than 100 MW capacity.

Turbine specifications are now being prepared to have 8 plant turbine with 80 psig first stage and 20 psig second stage. The power plant for this 225° C field may have two 35 MW units in operation by mid 1980. The estimated cost for the electricity generating plant installed will be $460/KW. A savings of $26 million in foreign exchange would result from this development.

STEAM

Geyser's steam price of 16.5 mills per kwh is about as inexpensive as geothermal energy can be produced today. The 1978 price of 16.5 mills per kwh is well below the competitive value of this energy. 20 mills per kwh would be a price more nearly reflecting its actual value in an area using oil or coal for electricity generation.

Plants to use a dry steam are the lowest in cost to build. PG&E's plant #15 is expected to cost $320/KW with provisions for H_2S treatment. This is an increase of 250% over the average of the 1961-1974 period. In the same period, the cost of electricity generated averaged about 5.6 mills per net kilowatt hour. 1979 operating costs will have increased the price of electricity to 25 to 30 mills per kilowatt hour.

Summarizing the preceding discussion on comparison of costs and resultant prices of electricity, we can tabulate oil, coal, nuclear vs. geothermal as follows:

	Oil	Coal	Nuclear
Fuel mills per kwh	20-23	9-11	6-7
Plant $/KW	300-400	580-950	800-1000
Electricity Busbar mills/kwh	33-44	35-36	32-34

	Geothermal		
	Steam	Flash 450° F	Binary
Fuel mills per kwh	14.5-16	16-20	26-30
Plant $/KW	320	450-475	500-1000
Electricity Busbar mills/kwh	22.5-24	25-30	40-48

RESERVE ESTIMATES

With these competitive conditions and an idea of the required investments in plant and fields, we can now estimate the potential reserves identified in relation to the proven reserve.

The proven reserves of the Geysers is now 908 megawatts. The potential reserves are another 1100 MW. To infer that the hot water area surrounding the dry steam reservoir will be productive of waters that will be used in flash steam plants is reasonable. Inferred hot water flash reserve should be approximately 1,000 MW.

The proven reserves in the Imperial Valley are 400 megawatts. Potential reserves of Brawley, East Mesa, Heber, Niland, and Westmoreland total 1600 MW. Reserves have been inferred with another 1,000 MW in these and similar anomalies within the province. Considerable work must be done on conversion systems, and deep drilling in the California portion of the Imperial Valley if another 5,000 MW are to be moved from the resource category into the reserve category in the next 20 years.

Coso, Lassen, Mono-Long Valley, Mammoth, Randsburg, can be credited with about 700 MW of inferred reserves. Sufficient drilling has not been done in these areas to estimate reservoir quality, water characteristics, and temperature distribution.

In the western Utah area, Roosevelt is the only area with proven reserves. It appears that sufficient testing and plant design work has been completed to assign 80 MW to that classification. 120 MW potential and 300 MW inferred reserves can be assigned to Roosevelt on information now available. The remainder of that general area including Cove Fort - Sulfurdale, Thermal-Black Mountain should have 1,000 megawatts potential reserves and 500 MW inferred.

Testing of potential areas in Nevada has not progressed to the stage where proven reserves can be assigned. The potential reserves of Phillips' three areas, and Chevrons' two areas in the northern half of the state, indicates 400 MW reserve. An additional 600 MW can be inferred on the basis of drilling data being extrapolated with geophysical surveys. With continued confirmation success in the Carson sink area, an additional 500 MW could be moved from resource to inferred reserves. New Mexico's Valles Caldera is considered as having 100 MW potential reserve. From the size of the anomaly and the temperature indicated by surface springs, an inferred reserve of another 300 MW should be assigned. This area has a total reserve of 400 MW.

Oregon does not have proven reserves except in the direct use of the heat contained in the subsurface waters around Klamath Falls. The exploration for geothermal energy useful for generation of electricity has been encouraging in the northeast extension of the Gerlach-Baltazor trend into Oregon from northwest Nevada. The Alvord area has 200 MW potential reserves and 100 MW inferred. Between Alvord and Vale Hot Springs another 400 MW can be inferred. An additional 300 MW can be inferred from other heat flow and geophysical survey work in the general area.

This table summarizes these reserve catagories.

SUMMARY

ELECTRICITY GENERATION RESERVES

	Proven (Measured) MW	Potential (Indicated) MW	Inferred (Geol-Geoph) MW
Geysers	908	1,100	1,000
Imperial Valley	400	1,600	1,000
Coso-Lassen, Long-Valley, Mammoth, Randsburg			700
Roosevelt	80	120	300
Cove Fort, Sulferdale, Black Mountain-Thermal		1,000	500
N. Nevada		400	600
New Mexico		100	300
Alvord Area		200	100
Alvord to Vale			400
Other Oregon SE			300
Subtotal	1,388	4,500	5,200
Total Reserves	11,188 MW		

The direct use of geothermal heat in the U.S. is on a local project basis except in Klamath Falls, Oregon and Boise, Idaho. Local greenhouse operations, individual processing plants in industrial and agricultural projects are found throughout the western U.S., Alaska, Texas and Southeast Appalachians. It is estimated these present direct uses represent proven reserves of 35 MW.

Reserves cannot be assigned to geopressure-geothermal projects. It is hoped the government research work in progress can develop sufficient data to provide inferred reserves in 20 years.

Reserves now identified in the three catagories total 11,088 MW. This rapid build up from the reserve of 500 MW existing just four years ago demonstrates an aggressive search for and investment in producing areas. The 164,000,000 barrels of fuel oil that will be saved annually for electricity generation when this is developed is about 1/10 the amount of direct use potential existing today.

An oil accummulation to provide 164,000,000 bbls per year for 30 years would require 4.9 billion bbls to be available for production. Consider that less than .2 of 1% of all wildcats drilled in the U.S. during the last four years discovered producible reserves over the life of the field greater than 1 mm bbls of oil.

To assess the impact of the development of this reserve now identified plus the stimulus such development will give to exploration requires an assumption that the governmental agencies believe indigenous sources of energy are necessary to the economy of the USA.

In 1975 the forecast of the growth of geothermal capacity spanned 5,000 MW to 20,000 MW on line by 1985. The forecast by B. Greider at the 1975 United Nations Symposium was that 6,000 MW capacity would be on line by 1985. This required a reserve of 11,000 megawatts be discovered. The reserve has been discovered. The majority of the prospects contributing to this growth were on federal lands. These same prospects were recognized to be primarily in a temperature range that during most of the productive lifetime the reservoir would produce fluids at less than 400° F. The basic assumption underlying these forecasts was that viable economic incentives for geothermal would be similar to ones for other natural resource developments.

Stanford Research Institute, The University of California, Riverside, and Science Application Inc. have each provided thoughtful studies on the effect of tax incentives for the development of geothermal resources. The effect of such tax treatment has been focused on the resulting price of electricity or upon how much income this would "shelter" for the producer.

Each study has sidestepped the critical question of how large a capacity can be economically developed from recognized prospects with the subject incentives. How many would be developed lacking such economic stimuli. The next question that should have been answered is: what is the flow back to government agencies in tax revenues if certain incentives are initiated? This demands careful analysis of the possibility of reduced tax flow from projects that are certain to be developed without the incentives versus the increased tax revenue from those projects that would not have been developed without the incentives.

Consideration of the dynamic effect of taxation regulations on an incipient industry will show a tremendous benefit to government agencies in increased tax revenues. Robert Rex prepared the following two illustrations demonstrating the flow of monies to federal, state, and county agencies for a single 48 net MW project on federal lands and the effect if 1,000 MW developed on federal leases.

ESTIMATED GOVERNMENT REVENUES FROM FIELD DEVELOPMENT PROGRAM

1000 MW PROJECT

10% Federal Royalty Payments	$1,462,500,000
Federal Income Taxes	1,243,750,000
State Income Taxes	1,398,125,000
Ad Valorem Taxes	345,625,000
	$4,450,000,000

ASSUMES:
25 MILS/KWH
30 YEAR PROJECT LIFE
6% ANNUAL INFLATION RATE

ESTIMATED GOVERNMENT REVENUES FROM FIELD DEVELOPMENT PROGRAM

EAST MESA 48 MW PROJECT

10% Federal Royalty Payments	$ 70,200,000
Federal Income Taxes	67,110,000
State Income Taxes	16,590,000
Ad Valorem Taxes	59,700,000
	$ 213,600,000

ASSUMES
25 MILS/KWH
30 YEAR PROJECT LIFE
6% ANNUAL INFLATION RATE

If the reserves now known on federal lands are developed additional ones will be added in the process of development and by the increased exploration attracted to the area of successful development. Five thousand megawatts production on federal lands and two thousand MW on non-federal lands should return to the government 903 million dollars in revenues each year over the first 30 years of the projects lives. 7.02 billion dollars would flow to the federal government as royalty, 9.4 billion as income tax. 2.3 billion would be allocated to the various states' income tax revenues and more than 8.4 billion dollars to local county governments as ad valorum taxes.

SUMMARY

In 1973 the geothermal reserves in the U.S. were 500 MW. Reserves identified since 1970 total about 11,100 MW. This is enough energy to supply the total electrical needs for 11,000,000 people. To generate the same electricity using fuel oil 164 million barrels per year would be needed. Five billion barrels of oil would need to be discovered to supply the equivalent energy for 30 years.

Geothermal energy can compete with the other types of energy now being used in the U.S. To do so, the energy must be available from its reservoir at a temperature above 400° F. Below this temperature, operating cost rise significantly as the number of wells to produce and reinject the fluid increases.

Tax incentives must be provided to encourage significant investment in the mid temperature hot water resources if this type of energy is to be developed.

The cost of the plants rise rapidly as the temperature of the reservoir decreases. The volume of fluid required to move through the system increases rapidly to supply the required heat. There are economic limits established by temperature that must be recognized. If the BTU content of a ton of coal drops, there is a point where it is not useable for power production. The same is true for oil and gas fluids as their associated water or inert gas ratio increases. Geothermal fluids quality and usefulness is also dependent upon its BTU content per unit volume produced. The building of power plants for mid temperature projects is critical to the utilization of this large resource.

For this reason, it is difficult to present a specific cost of electricity produced by broad types of resource. The probable range of prices for electricity generated from steam and hot water reservoirs today is:

	Mills/KWH
Steam 450° F and above	22.5 - 24
Hot water flash - below 400° F	36 - 50
above 400° F	25 - 30
Binary	40 - 48

The expected value of a geothermal project, the field costs and the resulting costs to generate electricity are affected by the interrelated variables such as:

- Temperature of fluids
- Composition of fluids
- Geology of reservoir
- Cost drilling
- Flow rate per well
- Well spacing
- Turbine system
- Operating costs.

Research must continue on how to make fluids with temperatures below 400° F useful. The technology is now mature. There are vast quantities of heat in this resource awaiting the solution to the economic problems of using this low grade heat.

Risk capital must be readily available in units of 10 to 15 million dollars at the beginning of exploration. Development to 400 MW may require up to 100 million dollars investment before payout of the first 50 MW unit is obtained. The investor with sufficient money to carry out a successful program will compare the return of invested capital offered by similar projects (utilizing similar technology and business know-how). The projects offering the best rate of return for similar risk and investment will usually be the ones selected for funding.

The biggest problem in obtaining risk capital is the uncertainty of the business. This includes the discrimination in tax treatment of hot water versus steam. This precludes being able to market the energy at competitive prices and obtain as favorable rate of return as other industries offer. Prospective investors should have assurance that government rules and regulations will encourage the discovery and use of this energy.

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APPENDIX

GEOPRESSURE - GEOTHERMAL RESERVOIRS

Tertiary basins around the world have been discovered to have reservoirs at greater than normal pressure gradients. These geopressured zones frequently have higher than normal geothermal gradients. Exploration and field development for oil and gas production in Texas and Louisiana has outlined an area of interest extending several hundred miles from the Rio Grande River to the Delta of the Mississippi parallel to the Gulf Coast. I have not recognized any reserves in this catagory.

The economics of developing this combination of kinetic energy, low grade heat energy, and methane, is unfavorable at this time. Uncertainty as to the producibility is caused by the knowledge that to have geopressure, the sand formations must be discontinuous and the reservoirs must be confined in a limited areal configuration. Without such limits, normal temperatures and pressures would exist. In the deeper reservoirs of the geopressured areas, higher temperatures have been reported by Louisiana State University personnel. These deeper reservoirs (18,000' to 19,000') are reported to be at temperatures above 400°F. The low permeabilities reported with the moderate reservoir thickness (400') will require a maximum producing rate of 20,000 bbls per day (instead of the 40,000 bbls usually used) per well if excessive drawdown is to be avoided. The wells would probably require 640 acre spacing to eliminate well interference effects. The producer-injector ratio should be planned for 1:1. However, an initial testing period for the first modules can confirm this assumption.

The Department of Energy plans a deep $6,000,000 well test of this type of geopressured prospect. The results will be valuable in trying to design a workable method to recover and use this very expensive submarginal energy accumulation. Tables III, IV, and V, synthesize my opinions.

Table III

GEOPRESSURE ECONOMICS

BASIS

Reservoir Thickness (assumed)	400'
Permeability/Ft.	Less than 10 md
Surface Pressure (desired)	3,000 PSI - 4,000 PSI
Flow Before Injection req'd	1.0 - 1.1 billion bbls
Time Before Injection	Less than 2 years
Minimum spacing producers (interference)	640 acres
Draw Down Limit	3500 PSI
Injection Pressure	5000 PSI
Net Methane in Solution	75 SCF/bbl

Table IV

GEOTHERMAL ECONOMICS

SCOPE FACILITIES

Field Size	200 MW
Barrels Per Year	600 Million
Barrels Per Day Per WL11	20,500
10 Wells Each	25 MW Unit
80 Producers	80 Injectors
Plant Net	200 x .85
Plant Load Factor	70%

Operating costs and taxes can only be estimated. It is certain they will not be less than those experienced in keeping a gas or oil field in operating for 30 years.

Table V

INVESTMENT & REVENUE

160 Wells @ $6 M̄ Eac. (includes surface-facilities)		$960 M̄
Heat @ .020/kwh	Gas @	$ 1.75 M̄CF
Energy Revenue		21.25 M̄/Yr
Gas Revenue		85.75 M̄/Yr
Revenue Total		$107.00 M̄/Yr.

EXPENSE

Operating Costs $200/Well/Day = $12 M̄/Yr

Property & State Tax 15% x Gross/Yr = 16 M̄

Total Expense = $28 M̄

INCOME

Income - $107M̄ - $28M) = $79 M̄

Net $79M x 50% (Income Taxes) = $39.5 M̄

Payout $960/$39.5 = 24 Years ROI = 4%

There are adequate problems to solve in utilization of geopressured-geothermal reservoirs. These are primarily related to geologic problems. Discontinuous sands form the reservoir rocks in geopressured systems. The lack of continuity prevents fluid moving to lower pressured zones in a natural adjustment to normal pressure results in the abnormal geopressures. This very discontinuity results in limited reservoirs of restricted areal extent.

In many geologic situations, faulting and fracturing provide the plumbing that allows geothermal fluids to move into the producing reservoirs. The vertical movement of fluids along these faults is thought to be an important factor necessary for high production rates over the long life required for energy production.

Geopressured reservoirs have no such plumbing, otherwise, their pressures would be normal. The sealed faults in the geopressured areas will cause rapid pressure decline unless produced volumes are compensated by having equal volumes reinjected into the same sand bodies. It is for this reason this source of energy must remain an energy resource with no defined reserves.

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UNITED STATES GEOLOGICAL SURVEY
GEOTHERMAL RESEARCH PROGRAM
FISCAL YEAR 1979

The U.S. Geological Survey's Geothermal Research Program is a multidisciplinary effort with the goal of understanding the nature, distribution, and energy potential of the Nation's geothermal resources. Knowledge gained from research activities of the program is used to provide reliable, documented estimates of the magnitude of these resources for use in planning a national energy policy. In addition, the program's work is applied to advancing the methodology of exploration for geothermal energy sources, to developing a systematic knowledge of the characteristics of natural geothermal systems that may affect their development, and to solving certain environmental problems that may be associated with the extraction of geothermal energy. The program is, therefore, divided into five broad categories:

1. National and regional resource inventory
2. Exploration and assessment technology
3. Resource characterization
4. Geologic controls of subsurface porosity and permeability
5. Geoenvironmental effects of geothermal production

A new geothermal resource assessment of the United States will be published in early 1979 as USGS Circular 790. This new assessment is the culmination of a 3-year effort to update and refine the first geothermal resource assessment of the U.S., published by the USGS in 1975 as Circular 726.

All of the geothermal energy produced to date has been from hydrothermal systems in permeable rock. Two types of geothermal environment, however, may represent even larger potential sources of energy--the geopressured zones of large sedimentary basins and hot dry rocks. For FY-79, the Geothermal Research Program has been funded to increase its effort in understanding the resource potential of these environments. Additionally, an increased emphasis is being placed on regional geothermal characterization and assessment of the Cascade Mountains of Washington, Oregon, and northern California. This is intended to be the beginning of a concerted effort over the next few years to achieve a better understanding of the active volcanic, tectonic, and hydrothermal processes that characterize the Cascades. The Cascade studies will include geologic mapping, petrologic study of hydrothermally altered areas, fluid geochemistry, and both regional and detailed geophysical surveys.

The Geothermal Research Program includes a wide variety of geologic, geochemical, geophysical, and hydrologic studies that are conducted within both the Geologic and Water Resources Divisions of the Geological Survey. The program is not organized as a line activity but is administered by the Geologic Division under the "lead division" concept. The program as a whole is managed by Robert L. Christiansen, Program

Coordinator (Menlo Park, California), under the direction of Robert I. Tilling, Chief of the Office of Geochemistry and Geophysics (Reston, Virginia). Donald E. White, senior scientist in geothermal research, is advisor to Christiansen and Tilling. Christiansen also directly coordinates geothermal investigations carried out in the Geologic Division; studies done in the Water Resources Division are coordinated by Franklin H. Olmsted (Menlo Park). The Geothermal Research Program supports research outside the USGS through a program of extramural grants and contracts managed by Donald W. Klick (Reston). Approximately 15 percent of the program's funds are designated for this extramural research. Klick also serves as Washington liaison between the Survey and other Federal agencies having geothermal programs.

The Geothermal Research Program is organized and managed separately from the activities of the Conservation Division related to geothermal leasing on Federal lands. However, much of the information produced by the Geothermal Research Program has a direct bearing on classification and evaluation of those lands for geothermal leasing. Timely and efficient exchange of information between these two activities is accomplished by joint planning and funding of certain data-gathering activities between the Research Program and the Conservation Division's lease-evaluation section. In addition, the Geothermal Research Program Coordinator maintains regular contact with the Conservation Division's Area Geothermal Supervisor.

Some activities of the Geothermal Research Program directly support some programmatic objectives of the Department of Energy, and DOE and its predecessors have provided some funding to increase the timeliness of those activities.

Until 1971, the USGS did not have a specifically organized and funded program of geothermal research and resource evaluation. Limited investigations of hot springs, geysers, and hydrothermal systems had been conducted since 1945 as part of the Geologic Division's continuing work in investigating the nation's energy and mineral resources. Congress first authorized a specific program of geothermal research in FY-72. The fiscal history of the program is shown below:

FY-71	$205,000 (part of ongoing Geologic Division program)
FY-72	$665,000
FY-73	$2,255,000
FY-74	$2,555,000 (also $300,000 from NSF and $120,000 from AEC)
FY-75	$8,966,000 (also $343,000 from ERDA)
FY-76	$9,114,000 (also $320,000 from Conservation Division, USGS and $315,590 from ERDA)
FY-77	$9,243,000 (also $130,705 from Conservation Division, USGS and $532,000 from ERDA)
FY-78	$9,438,000 (also $116,731 from Conservation Division, USGS and $1,011,823 from DOE)
FY-79	$11,863,000

The internal work of the Geothermal Research Program is carried out in individual projects. These fall into six topical categories:

1. General studies of geothermal systems and the transfer and storage of geothermal heat.
2. Regional geothermal investigations.
3. Studies of hydrothermal systems and fluid geochemistry.
4. Studies of volcanic systems and magma chambers.
5. Studies of geopressured geothermal systems.
6. Development of geochemical and geophysical techniques for geothermal exploration and assessment.

The project titles, project chiefs and their locations, and a brief description of each project are listed following.

GEOTHERMAL SYSTEMS; HEAT TRANSFER AND STORAGE

1. Geothermal Resource Assessment - L. J. Patrick Muffler (Menlo Park)
   Inventory of the U.S. geothermal resources and resource base.

2. Geothermal Resource Evaluation (GEOTHERM) - James R. Swanson (Menlo Park)
   Creation of a computer file to store and retrieve numerical data on geothermal fields.

3. Geothermal Geophysics - Don R. Mabey (Salt Lake City)
   A group of geophysical studies including aeromagnetic and gravity surveys and regional analysis of geothermal areas. Includes systematic acquisition and compilation of data on designated Known Geothermal Resource areas to support Conservation Division's lease-evaluation activities.

4. Teleseismic and Microearthquake Geothermal Studies - H. M. Iyer (Menlo Park)
   Delineation of magma systems and the deep structure of geothermal areas through the use of microearthquake surveys and teleseismic P-wave traveltime delays.

5. Geothermal/Tectonic Seismic Studies - Craig S. Weaver (Menlo Park)
   Detailed study of the seismicity of selected geothermal areas and their tectonic framework.

6. Active Seismic Exploration of Geothermal Sources - David P. Hill (Menlo Park)
   Detailed determination of the velocity structure of the crust and upper mantle for use in studying the composition and pressure-temperature characteristics of geothermal systems.

7. Geothermal Processes, Heat Flow - Arthur H. Lachenbruch (Menlo Park)
   Theoretical studies of heat flow combined with field observations in the Western United States to increase understanding of the processes of heat and mass transport in the crust and upper mantle, and of the nature and distribution of geothermal resources.

8. Physics of Geothermal Systems - Thomas C. Urban (Menlo Park)
   Measurement of temperatures and thermal properties in drill holes and integration of available geologic and hydrologic information to better understand temperature distribution and heat transfer within geothermal systems.

9. Geothermal Reservoirs - Manuel Nathenson (Menlo Park)
   Investigation of convective heat flow in geothermal reservoirs to refine methods of assessing geothermal resources.

10. Physics of Geothermal Fluid Flow - William N. Herkelrath (Menlo Park)
    Laboratory experiments to understand how high temperature gradients effect multiphase fluid flow through porous media.

11. Numerical Modelling of Liquid Geothermal Systems - Michael L. Sorey (Menlo Park)
Development of numerical models describing heat transfer and fluid flow in three-dimensional, liquid-saturated porous media.

12. Multiphase Finite-Element Models - James W. Mercer (Reston)
Development of mathematical models for predicting the spatial and temporal behavior of hot-water and vapor-dominated geothermal reservoirs.

13. Mathematical Modeling of Energy Transport in Multiphase Ground Water Systems - Allen F. Moench (Menlo Park)
Mathematical modeling of multiphase geothermal systems to determine heat flow, temperature and pressure distributions, and convection rates.

14. Geothermal Fission-track Studies - Charles W. Naeser (Denver)
Use of the thermal sensitivity of fission tracks in apatite to develop a better understanding of the thermal histories of volcanic and crystalline-basement rocks in geothermal systems.

15. Geothermal Petrophysics - Gary R. Olhoeft (Denver)
Laboratory measurement of the physical properties of geothermal materials under conditions simulating their natural environment.

16. Rocks Under Geothermal Conditions - Louis Peselnick (Menlo Park)
A study of elastic-wave propagation in rocks at high temperature and pressure for use in detecting and locating geothermal energy sources.

17. Pressurized Fractures in Hot Rock - David D. Pollard (Menlo Park)
A study of the physical processes associated with the initiation and propagation of large fluid-filled fractures in hot rock.

18. Subsidence Research in Geothermal Areas - Francis S. Riley (Denver)
Monitoring of ground movements in geothermal areas for a base-line record and to develop an understanding of the mechanism of subsidence caused by withdrawal of geothermal fluids.

19. Intermediate-Depth Drilling - J. Glenn Blevins (Menlo Park)
Drilling to depths to 2000 feet for aquifer testing, heat-flow measurements, and hydrologic data in geothermal areas.

REGIONAL INVESTIGATIONS

1. Regional Geothermal Hydrology of Southwestern Montana - Robert B. Leonard (Helena)
   Determination and description of the nature and distribution of thermal springs in southwestern Montana.

2. Hydrologic Data on Geothermal Systems, Idaho - E. G. Crostwaite (Boise)
   Collection of hydrologic data from shallow and intermediate depth wells on and near the Snake River Plain, Idaho, for use in understanding the occurrence and flow of ground water in the basin.

3. Geothermal Studies of the Snake River Plain - S. S. Oriel (Denver)
   Geologic mapping of the Snake River Plain, Idaho, to provide a framework for geothermal investigations.

4. Snake River Plain Geoelectric Studies - William D. Stanley (Denver)
   Investigation of the Snake River Plain-Yellowstone region using deep electrical sounding techniques.

5. Geothermal Potential of Owyhee County, Idaho - E. B. Ekren (Denver)
   Geologic mapping and stratigraphic study to determine the geologic features of probable geothermal reservoir rocks of the western Snake River Plain and its western margin and identification of possible geothermal targets within the area of study.

6. Oregon Geothermal Reconnaissance - Norman S. MacLeod (Menlo Park)
   Evaluation of the geothermal potential of central and southeastern Oregon.

7. Geothermal Hydrologic Reconnaissance, Oregon - Edward A. Sammel (Menlo Park)
   Description and evaluation of several geothermal systems in Oregon including the Klamath Falls, Newberry, Summer Lake, and Warner Valley Areas.

8. Hydrologic Reconnaissance of Geothermal Areas in Nevada and California - Franklin H. Olmsted (Menlo Park)
   Study of the hydrology and geology of several hydrothermal systems in northern and central Nevada and formulation of conceptual models of those systems for which the most data are available.

9. Black Rock Desert Geothermal Studies - Alan H. Welch (Carson City)
   Hydrologic and geophysical investigation of hydrothermal systems in the western Black Rock Desert, Nevada, to determine the systems' fluid recharge and discharge and total heat budget.

10. Imperial Valley Seismic Geothermal Studies - Gary Fuis (Menlo Park)
    Investigation of the relation between earthquakes and geothermal areas, and monitoring changes in seismicity that may result from commercial geothermal development.

11. Geothermal Hydrology of the Lower Coachella Valley, Southeastern California - James H. Robison (Menlo Park)
Description of the geohydrologic framework of the Coachella Valley and how it may relate to geothermal systems; evaluation of other data that may indicate geothermal systems in the area.

12. Alaska Geothermal Reconnaissance - Thomas P. Miller (Anchorage)
Evaluation of the geothermal resources of Alaska, especially the Aleutian volcanic arc and the Wrangell Mountains.

HYDROTHERMAL SYSTEMS AND FLUID GEOCHEMISTRY

1. Thermal Waters - Donald E. White (Menlo Park)
Investigation of the origins and characteristics of thermal waters.

2. Rock-Water Interactions - Robert O. Fournier (Menlo Park)
Development of criteria for estimating conditions deep in hydrothermal systems using chemical compositions of fluids from thermal springs and wells.

3. Geochemical Indicators - Alfred H. Truesdell (Menlo Park)
Application of chemical and isotopic methods to the study of geothermal systems to determine subsurface temperatures, flow directions, origins and ages of recharge waters, and the influence of subsurface processes on the chemical and isotopic compositions of geothermal fluids.

4. Geochemical Studies of Geothermal Systems - Ivan Barnes (Menlo Park)
Collection and analyses of liquid and gas samples from thermal springs and wells for chemical and isotopic data that can be used to estimate reservoir temperatures, outline favorable areas for geothermal exploration, identify potential pollution problems, and estimate recharge-discharge relations.

5. The National Center for the Thermodynamic Data of Minerals - John L. Haas, Jr. (Reston)
Critical evaluation and compilation of published thermodynamic data from international sources for minerals found in geothermal environments.

6. Trace Elements - Everett A. Jenne (Menlo Park)
Anaylsis of trace elements discharged from geothermal springs and determination of how these elements are dissipated in the natural environment.

7. Oxygen Isotopes, Geothermal - James R. O'Neil (Menlo Park)
Analysis of light stable isotope ratio in geothermal fluids and minerals.

8. Isotope Geochemistry of Hydrothermal Fluids - Tyler Coplen (Reston)
Analysis of deuterium of geothermal fluids.

9. Stable Isotopes and Ore Genesis, Geothermal - Robert O. Rye (Denver)
Studies of sulfur isotopes and other stable isotope systems at Yellowstone National Park.

10. Electrochemistry of Minerals - Motoaki Sato (Reston)
Development of instrumentation for monitoring the CO_2 component of volcanic and geothermal gases.

11. Geology of Yellowstone Thermal Areas - Melvin H. Beeson (Menlo Park)
A study of the structural controls of hydrothermal systems and the nature of hot spring deposits and alteration products in Yellowstone National Park.

12. Hydrothermal Alteration in the Cascades - Melvin H. Beeson (Menlo Park)
Detailed field mapping and laboratory petrological and mineralogical studies of selected active and fossil geothermal systems of the Western and High Cascades.

13. Geology of Thermal Areas in and around Lassen Volcanic National Park - L. J. Patrick Muffler (Menlo Park)
A geologic study of the volcanic rocks south and east of Lassen Peak, California, to provide the geologic framework for geochemical studies of gases and water from Lassen thermal areas.

14. Pre-Tertiary Geology of The Geysers/Clear Lake Areas, California - Robert J. McLaughlin (Menlo Park)
Determination of the structure of Pre-Tertiary rocks in The Geysers/Clear Lake geothermal area and development of an understanding of the relation between structure and the occurrence of geothermal fluids.

15. Earthquake Studies in The Geysers/Clear Lake Region - Charles G. Bufe (Menlo Park)
Determination of the relationship between present seismicity at The Geysers/Clear Lake area and regional electronics and local deformation associated with the magma body presumed to exist at depth.

16. Gas Geochemistry in Hawaii - Tom Casadevall (Hawaiian Volcano Observatory)
Study of volcanic and geothermal gases associated with Kilauea and Moana Loa volcanoes.

17. Geothermal Reconnaissance of the Salt River Valley, Arizona - Philip P. Ross (Flagstaff)
Hydrologic studies to determine the extent and distribution of geothermal waters in the western Salt River Valley.

18. Geothermal Studies of the Vein System at Creede, Colorado - P. M. Bethke (Reston)
Investigation of the thermal, chemical, and isotopic evolution of ancient geothermal fluids in the Creede ore-forming system.

VOLCANIC SYSTEMS AND MAGMA CHAMBERS

1. Regional Volcanology - Robert L. Smith (Reston)
Classification, characterization, and geothermal evaluation of volcanic systems in the Western United States.

2. Geothermal Geochronology - Marvin Lanphere (Menlo Park)
Radiometric dating of igneous rocks from geothermal areas by K/Ar methods, and development of a thermoluminescence method for dating young volcanic rocks.

3. C-14 Dating, Geothermal - Stephen W. Robinson (Menlo Park)
Dating of young volcanic events using the C^{14} method.

4. Tephrochronology, Central Region - Glen A. Izett (Denver)
Integrated study of volcanic ash beds by chemical, mineralogical, isotopic-age, and paleomagnetic methods in order to date Cenozoic continental sedimentary units, to relate the ashes to their source areas, and to determine aspects of the eruptive history and magmatic evolution of certain volcanic areas.

5. Geothermal Paleomagnetic Studies - Sherman Grommé (Menlo Park)
Reconstruction of the history of Holocene geomagnetic secular variation as a basis for dating young volcanic rocks, and the application of other paleomagnetic and rock-magnetic techniques to the study of volcanic geothermal systems.

6. Geophysical Characterization of Young Silicic Volcanic Fields - David L. Williams (Denver)
Characterization of volcanic geothermal areas using gravity, aeromagnetic and other geophysical data.

7. Kinetics of Igneous Processes - H. R. Shaw (Menlo Park)
Application of computer analysis to study of mass and energy balances in the evolution of high-level silicic magma chambers and the interaction between magma, country rock, and hydrothermal systems.

8. Roots of Calderas and Fossil Geothermal Systems - Peter W. Lipman (Denver)
Investigation of caldera-related structures that are sites of fossil hydrothermal systems in order to determine structural relations between volcanic and plutonic features that constrain the P-V-T-X conditions of hydrothermal circulation, alteration, and mineralization.

9. San Francisco Volcanic Field - Edward W. Wolfe (Flagstaff)
Geological studies designed to determine whether magma exists in the crust under the San Francisco volcanic field of north-central Arizona.

10. Springerville Volcanic Field, Arizona - Edward W. Wolfe (Flagstaff)
Areal geologic mapping of the Springerville volcanic field in east-central Arizona.

11. Petrology of the Yellowstone Plateau Volcanic Field - Robert L. Christiansen (Menlo Park)
Investigation of origin and evolution of the Yellowstone magmas, and geochemical studies of zoned silicic magma chambers.

12. Yellowstone Seismic Analysis - Andrew M. Pitt (Menlo Park)
Study of seismicity patterns in the Yellowstone region to determine how these patterns relate to the fluid circulation, thermal regime, and tectonics of the region.

13. Geology of the Coso Mountains - Wendell A. Duffield (Menlo Park)
Study of the geology, structural setting, and volcanic evolution of the late Cenozoic Coso volcanic field.

14. Long Valley-Mono Basin Geologic Studies - Roy A. Bailey (Reston)
Detailed geologic mapping and petrologic study of the Long Valley caldera in east-central California.

15. Clear Lake Volcanics, California - B. Carter Hearn, Jr. (Reston)
Geologic mapping, isotopic dating, and geochemical studies of the Clear Lake volcanic field in northern California.

16. Volcanology and Petrology of Mt. Shasta - Robert L. Christiansen (Menlo Park)
A study of the volcanic evolution of Mount Shasta, California, and its relation to surrounding volcanic areas.

17. Medicine Lake Volcanic Field, California - Julie M. Donnelly (Menlo Park)
Geologic mapping and studies of the geochemistry and geochronology of the Medicine Lake volcano to determine the geothermal potential of this young volcanic system.

18. Mount Mazama (Crater Lake), Oregon - Charles R. Bacon (Menlo Park)
Detailed geologic mapping and geochemical studies of Mt. Mazama, a collapsed volcano in south-central Oregon that offers a unique opportunity to decipher the evolution of a shallow silicic magma reservoir that may have present-day analogues elsewhere in the Cascade Range.

19. Hawaiian Geothermal Studies - Robert W. Decker (Hawaiian Volcano Observatory)
Geologic, geophysical, and geochemical studies to determine the structure and physical properties of shallow magma reservoirs and hydrothermal systems, especially at Kilauea volcano.

20. Seismic Studies of Hawaiian Magma Reserviors - Frederick W. Klein (Hawaiian Volcano Observatory)
Analysis of seismicity to determine the location, physical properties, and behavior of magma chambers beneath Kilauea volcano and its rift zones.

21. Volcano Deformation Studies - James Dieterich (Menlo Park)
A study of surface deformation and tilting around Kilauea and Mauna Loa volcanoes, Hawaii, to better understand the geometry and mechanics of shallow magma chambers.

22. Potential Methods for Subsurface Magma Mapping, Kilauea Volcano, Hawaii - Charles J. Zablocki (Denver)
Geoelectrical studies designed to characterize the magma body under Kilauea volcano, Hawaii, and to understand hydrothermal systems related to the volcano.

GEOPRESSURED GEOTHERMAL SYSTEMS

1. Geopressured-Geothermal Resources of the United States - Raymond H. Wallace, Jr. (Bay St. Louis)
   Study of the hydrology of the geopressured Tertiary sediments of the Gulf Coast Region.

2. Stratigraphy and Sedimentation of Geopressured Zones - Richard Q. Foote (Corpus Christi)
   Subsurface geologic studies of the offshore and deeper onshore geopressured zones of the Gulf Coast to characterize their stratigraphic framework and depositional environments, and ultimately to predict the extent and characteristics of source beds and reservoir rocks for waters charged with methane gas.

3. Geophysical Detection of Geopressured Zones - Richard Q. Foote (Corpus Christi)
   Development of geophysical methods for detecting and delineating lateral and vertical lithologic successions in the geopressured zones of the Texas-Louisiana Gulf Coast.

4. Geochemistry of Geopressured Systems - Yousif K. Kharaka (Menlo Park)
   Study of the geochemistry and mineralogy of the Gulf Coast geopressured systems to develop guidelines for delineating favorable exploration areas and identifying potential pollution, waste disposal, and corrosion problems associated with their production.

DEVELOPMENT OF GEOTHERMAL-EXPLORATION TECHNIQUES

1. Volatile Elements and Compounds in Geochemical Exploration - Margaret E. Hinkle (Denver)
   Construction and field testing of a helium "sniffer" to test the use of helium concentration in soil gases as a method of geothermal exploration.

2. Stable Isotopes, Geothermal - Irving Friedman (Denver)
   Evaluation of the Pallman method (sucrose inversion) in determining anomalous shallow geothermal gradients; application of obsidian-hydration dating to young volcanic rocks.

3. Remote Sensing, Geothermal - Kenneth Watson (Denver)
   Development of thermal infrared techniques for geothermal resource exploration.

4. Engineering Geophysics - Hans D. Ackermann (Denver)
   Determining relations between the rock properties of geothermal systems and their seismic-wave transmission properties by seismic measurements in the field and application of these relations to problems of geothermal exploration.

5. Geothermal Regional Studies - Robert Simpson (Denver)
Analysis of regional geophysical data pertinent to geothermal studies.

6. Potential-field Methods - Bimal Bhattacharyya (Denver)
Inversion of aeromagnetic data to provide thermal models of geothermal regions.

7. Resistivity Interpretation - Adel Zohdy (Denver)
Development and application of solutions for inversion of resistivity data in geothermal areas.

8. Electrical Techniques for Shallow to Medium-Depth Exploration for Geothermal Systems - Donald B. Hoover (Denver)
Development of self-potential and audiomagnetotelluric techniques for more effective use in the exploration of geothermal systems.

9. Development and Evaluation of Magnetotelluric and Telluric Methods - James E. O'Donnell (Denver)
Evaluation and improvement of magnetotelluric and telluric survey techniques in prospecting for geothermal resources.

10. Physical Properties of the Crust and Upper Mantle by Geomagnetic Variation - David V. Fitterman (Denver)
Development and application of the geomagnetic variation sounding technique for use in estimating the physical state of the crust and upper mantle, with emphasis on the geothermal potential of large regions.

11. Variometer Array and Transient Electromagnetic Investigations on the Sierran Front and Rio Grande Rift - James N. Towle (Denver)
Determination of crustal and upper-mantle structure in regions of geothermal potential using geomagnetic array techniques.

12. Electromagnetic Modeling and Inversion of Controlled-Source Measurements - Walter L. Anderson (Denver)
Development of numerical techniques and computer programs for electromagnetic modeling and inversion of controlled-source electromagnetic data.

13. Geophysical Instumentation and Field Support - Frank C. Frischknecht (Denver)
Design, construction, and procurement of new geophysical equipment for use in geothermal research and exploration; repair and maintenance of existing equipment; and field support of geophysical operations.

14. Borehole Geophysics as Applied to Geothermal Research - W. Scott Keys (Denver)
Development of accurate, reliable geophysical logging systems for geothermal wells.

Projects Current as of October 1, 1978
EXTRAMURAL RESEARCH GRANTS AND CONTRACTS

1. UNIVERSITY OF ALASKA - Donald L. Turner
   Downhole fission track - K/Ar age determinations and the measurement of perturbations in the geothermal gradient.

2. UNIVERSITY OF ARIZONA - Denis L. Norton
   Chemical mass transfer between circulating fluids and rocks in modern geothermal systems.

3. BROWN UNIVERSITY - John Hermance
   Modeling the magnetotelluric response of three-dimensional geothermal structures.

4. BROWN UNIVERSITY - Joseph P. Kestin
   Thermophysical properties of water substances and of aqueous solutions.

5. BROWN UNIVERSITY - E. M. Parmentier
   A modeling study of physical processes in cooling intrusions and their relation to the evolution of geothermal systems.

6. UNIVERSITY OF CALIFORNIA, BERKELEY - Frank Morrison
   Interpretation of self-potential data from geothermal areas.

7. UNIVERSITY OF CALIFORNIA, SAN DIEGO - Harmon Craig
   Isotope and chemical studies of geothermal gases.

8. UNIVERSITY OF CALIFORNIA, SAN DIEGO - John M. Goodkind
   A study of gravity variations as a monitor of water levels at geothermal sites.

9. COLORADO SCHOOL OF MINES - George V. Keller
   Evaluation of methods for deep exploration of the earth.

10. COLORADO SCHOOL OF MINES - Charles H. Stoyer
    Automatic inversion of time-domain electromagnetic data by catalog look-up.

11. ENSCO, INC. - Edward Page
    Special geothermal ground noise experiment.

12. GEORGIA INSTITUTE OF TECHNOLOGY - Robert P. Lowell
    Convection in narrow vertical spaces.

13. UNIVERSITY OF HAWAII - Murli H. Manghnani
    Laboratory investigation of the seismic and thermal properties of basalts to melting temperatures.

14. UNIVERSITY OF NEVADA, RENO - Keith Priestley
    Detailed seismic characterization of geothermal subprovinces in central Nevada.

15. NEW MEXICO STATE UNIVERSITY - Chandler A. Swanberg
The correlation among water chemistry data, regional heat flow, and the geothermal potential of the western U.S.

16. PURDUE UNIVERSITY - Lawrence W. Braile
Support of seismic refraction profiling research in Yellowstone National Park and the Snake River Plain.

17. SAN DIEGO STATE UNIVERSITY - Gordon Gastil
Reconnaissance study of thermal springs in the Peninsula Ranges of southern and Baja California.

18. SOUTHERN METHODIST UNIVERSITY - David D. Blackwell
Heat flow study and geothermal resource analysis of the Snake River Plain and margins, Idaho.

19. SOUTHERN METHODIST UNIVERSITY - David D. Blackwell
Workshop on thermal measurements applied to geothermal exploration.

20. SOUTHERN METHODIST UNIVERSITY - Wayne J. Peeples
Simultaneous inversion of data from disparate geophysical experiments.

21. STANFORD UNIVERSITY - David M. Boore
Evaluation of intermediate period seismic waves as an exploration tool for geothermal areas.

22. SYSTEMS, SCIENCE AND SOFTWARE, INC. - T. David Riney
Integrated model of the shallow and deep hydrothermal systems in the East Mesa area, Imperial Valley, California.

23. UNIVERSITY OF TEXAS, DALLAS - Ronald W. Ward
Evaluation of geothermal systems using teleseisms.

24. UNIVERSITY OF TEXAS, DALLAS - Ronald W. Ward
Workshop on active and passive seismic methods applied to geothermal systems.

25. UNIVERSITY OF UTAH - David S. Chapman
Delineation of heat flow provinces in Utah.

26. UNIVERSITY OF UTAH - William P. Nash and William Parry
Petrology and geochemistry of the Blackfoot Reservoir region, southeastern Idaho.

27. WEIZMANN INSTITUTE OF SCIENCE - Emanuel Mazor
Evaluation of nobel gases in the exploration for geothermal energy.

28. WOODS HOLE OCEANOGRAPHIC INSTITUTION - William J. Jenkins
Mapping of volcanic and conducted heat flow sources for thermal springs in the western U.S. using helium isotopes and other rare gases.

29. WOODWARD-CLYDE CONSULTANTS - George E. Brogan
Faults and occurrences of geothermal anomalies.

Notes - Bob C.

Focus of Program - Regional Resource Assessment

Categories
1. National/regional inventory
2. resource characterization
3. expl/assess technology
4. geologic controls - porosity/perm
5. Geo environmental effects.

ACCOMPLISHMENTS

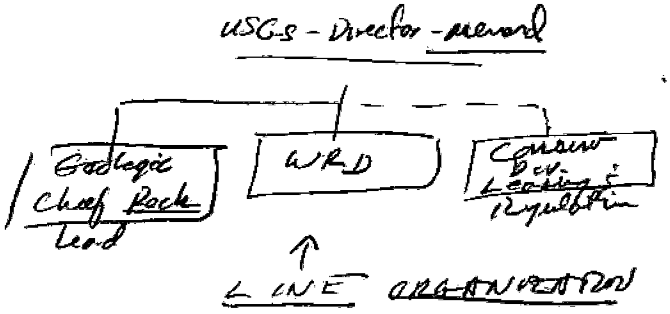
1. Fundamental Concepts - develop &
   - document: vapor dominated & water dominated
   - geochem. thermometers
   - isotope studies
2. National GT Resource Assess: 1975; 1978
3. Regional Assessments, characterization
   Long Valley
   Coso
   The Geysers - Clear Lake
   Yellowstone
   Snake River Plain
   San Francisco Volcanic Field
   Gulf Coast geopressured
4. Key Interpretations
   - geopressured
   - instrumentation, techniques
     (Keys, MT
5. Instrumentation/Technique Development

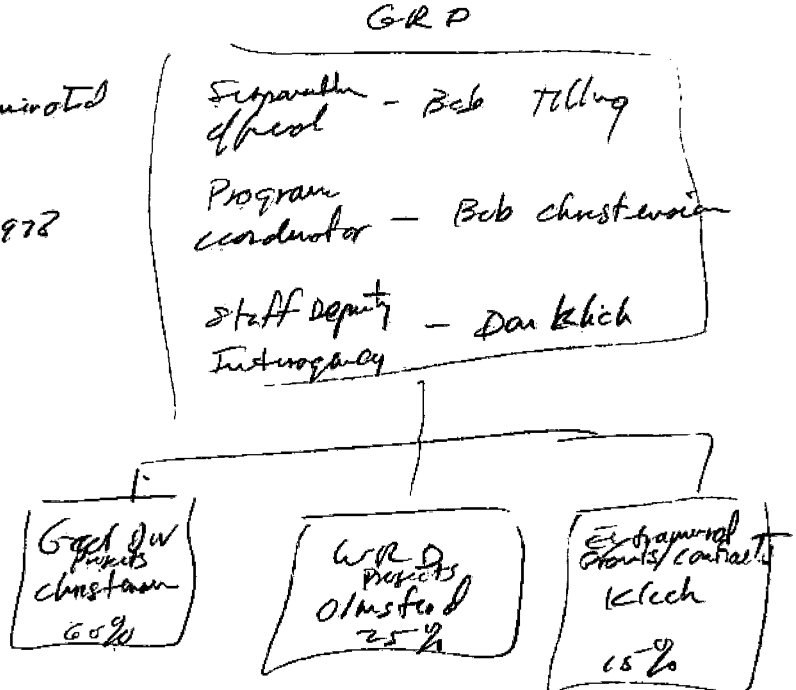
FY79

Publications
1. Circ 790
2. Geysers
3. Coso

Complete Major Field Studies
1. Snake River Plain
2. Raft River
3. San Francisco Volcanic Field

INITIATE NEW STUDY
- Cascades





Targets for Reduction

$2M cuts to come from
- extramural research grants - back to prev. level
- contracted gp surveys
- fewer areas integrated topical study
- less instrumentation & techniques

Continue Activity

logging
subsidence
induced seismicity
rock mechanics

SubJ
GTHM
GRAO

GEOTHERMAL RESOURCE ASSESSMENT OF THE NEW ENGLAND STATES

Gerald P. Brophy
Amherst, Massachusetts

Work Performed Under Contract DE-FC07-80RA50272

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Geothermal Resource Assessment
of the New England States

Introduction

On July 1, 1980, a two year program to conduct an assessment of the geothermal resource potential of the New England region (Fig. 1) was initiated under contract DE-FC07-80RA50272 between the Department of Energy and Amherst College of Amherst, Massachusetts, at a funding level of $65,000. Subsequently a six month no-cost extension was granted to terminate the study at the end of 1982. Most of the field work was conducted during the summer months, with laboratory work and literature searches being pursued during the academic year.

Even though, for geologic reasons, there appeared to be only a small possibility that hydrothermal geothermal resources might occur in the region, the existence of warm springs in western Massachusetts, the abnormal radioactivity in certain plutonic rocks in the region, and the high population and industrial density justified a survey at a low level of funding.

Since modern day earth scientists, except for hydrologists and ground water geologists, pay little or no attention to springs and their characteristics, it was necessary to go back and pursue the early geological literature concerned with New England and this in itself raised a problem. Early investigators wrote in a most prosaic style and rarely had indices in which specific features were listed, so often it was necessary to read an entire work in search of clues to

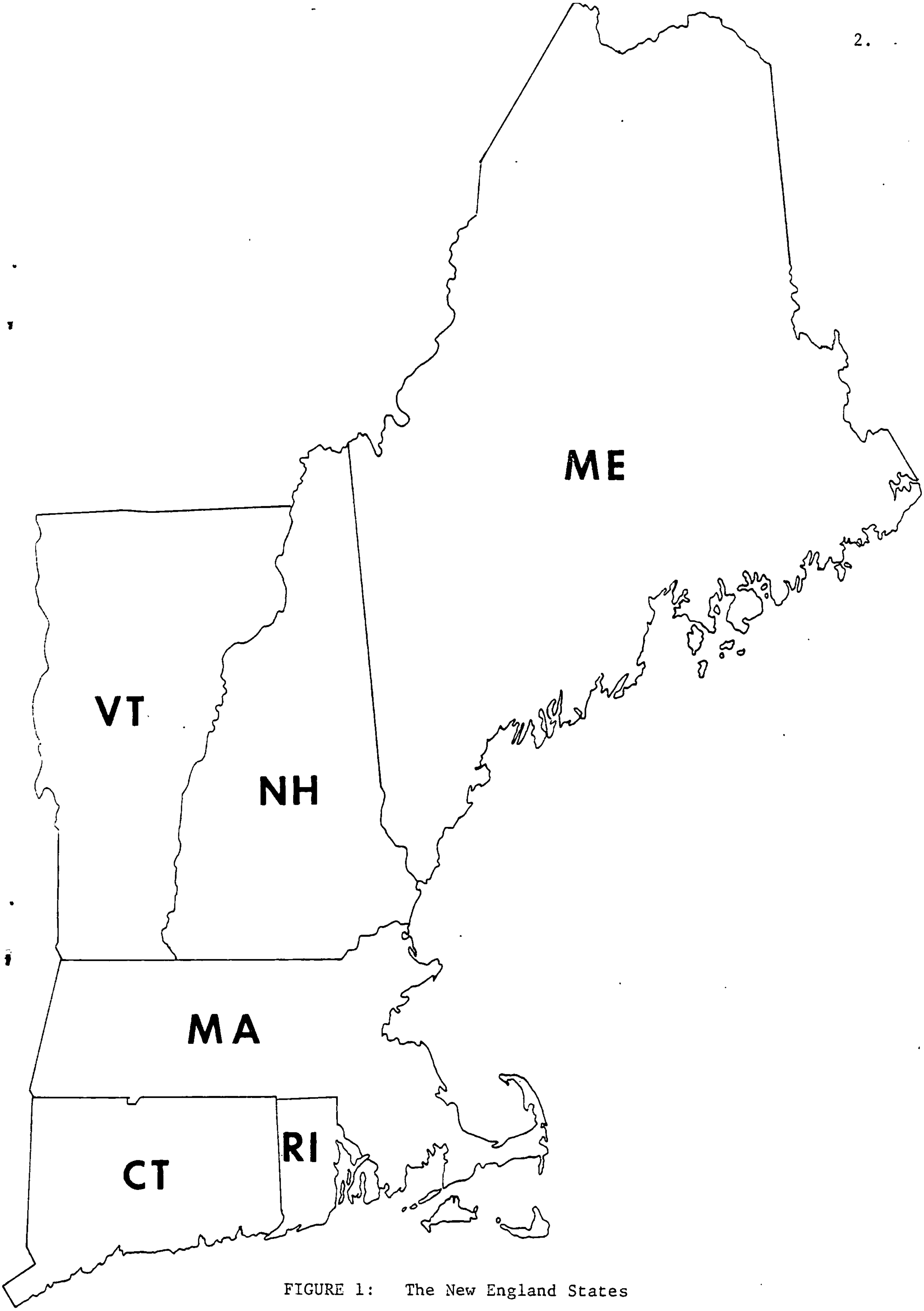

FIGURE 1: The New England States

springs of unusual character. Within these works the location of features are also vague and frequently given in terms of the current land owner and structures.

Early visits were made to the offices of the State Geologist, the State Energy Office, and the Water Resources Division Office of the U. S. Geological Survey, in search of information relating to springs and wells in the region. Compilation of geological and geophysical data have been made and compared in search of areas that could serve as targets for more detailed investigations.

Results of the Survey

With the exception of Sand Springs in Williamstown, Massachusetts, there are no identifiable hydrothermal geothermal resources in the New England region. The radioactive plutons of the White Mountains of New Hampshire do not, apparently, contain sufficient stored heat to make them a feasible target for an induced hydrothermal system such as exists at Fenton Hill near Los Alamos, New Mexico. The only potential source of low grade heat is the large volume of ground water contained within the unconsolidated sediments related to the Pleistocene glaciation of the region.

During the course of the survey an unusual and unexplained thermal anomaly was discovered in St. Johnsbury, Vermont, which is described towards the end of this report.

Summary of the Geologic History of New England

The oldest exposed rocks in New England (Plate I) are part of the Grenville Group of Precambrian age and crop out in the core of anticlinorial uplifts in western Vermont, Massachusetts and Connecticut. These rocks contain a long history, which includes repeated periods of sedimentation, deformation, metamorphism and intrusion. Rocks of Grenville age are believed to underlie virtually all of New England. The Grenville orogeny ended about 950 million years ago.

In Late Precambrian time rifting of the landmass containing the Grenville rocks occurred producing what some geologists term the "proto-Atlantic" ocean. Late Precambrian and Early Paleozoic sediments and volcanic material were deposited forming a continental shelf, slope and rise. Present day western New England contains rocks that were probably formed on the continental slope, with volcanic island arcs farther to the east. Continued erosion of the land mass to the west and north permitted the encroachment of the ocean westward creating large epeiric seas covering most of New England and the region to the west by Late Cambrian time and into Ordovician time.

The "proto-Atlantic" ocean began to close by Middle Orodvician time and deformation commenced with the advent of the Taconic orogeny. This deformation caused folding, thrusting, uplift and granodiorite intrusions of the Oliverian and Highlandcroft Magma Series (Plate II). The orogeny affected northern Maine and western New England and adjacent New York east of the Hudson River producing an elevated land mass. Erosion and sedimentation produced another sequence of continental margin sediments in Silurian and Devonian times but situated farther to the east in central Vermont, Massachusetts and Connecticut.

All of New England was again subjected to intense deformation (the Acadian orogeny) during Late Devonian time, producing intense metamorphism and intrusion of the New Hampshire Magma Series (Plate II). Erosion of the resulting mountain chain produced deltaic deposits that spread over much of the region during Pennsylvanian time. Large swampy areas developed on the deltaic deposits ultimately producing coal. These deposits are preserved today in Rhode Island and adjacent Massachusetts in the Narragansett Basin (Plate I).

In Late Pennsylvanian time or Early Permian time deformation again affected the region during the Appalachian orogeny, which in New England caused the folding, low grade metamorphism and granitic intrusion (Narragansett Pier granite) in Rhode Island and eastern Connecticut and Massachusetts.

Rifting began in Late Triassic time as a result of regional warping and associated faulting. Nonmarine, red fluvial and dark lacustrine sediments and basalts filled the rift valleys and basins into Jurassic time, creating the rock sequence now preserved in the Connecticut River Valley of Massachusetts and Connecticut and a much smaller basin in southwestern Connecticut.

In Late Jurassic time the present Atlantic Ocean began to open and the present continental shelf, slope and rise began to develop. While the oldest dated rocks in the shelf pile are of Jurassic age the oldest exposed rocks (at Martha's Vineyard) are of Cretaceous age. Associated with the opening of the Atlantic Ocean was the formation of a large group of calderas during Jurassic and Cretaceous time. The calderas and associated volcanic activity were centered in the middle of New Hampshire forming the alkalic igneous rocks of the White Mountain Magma Series (Plate II).

With the end of the volcanic activity the New England region has been subject to erosion with the exception of the advance of continental glaciers during Pleistocene time. The terminal morraines of the last advance are found in Massachusetts on Cape Cod, Martha's Vineyard and Nantucket Island. With the retreat of the ice sheet glacial till and lake deposits were spread unevenly over the entire region.

Tectonic Setting

The entire region of New England is essentially the northern extension of the Appalachian Mountains orogenic belt which in New England has been divided by Zen (1968) into several broad zones. (Fig. 2).Each of the zones forms a tectonically distinct geologic unit and usually has a distinct stratigraphy. It is perhaps easiest to discuss the zones from west to east across the structural grain of New England.

The westernmost zone associated with the Appalachian orogenic belt lies mostly outside of New England. This zone, termed the foreland, consists of rocks that are chiefly Cambrian to Middle Ordovician quartzites and carbonate rocks overlain by Middle Ordovician shale. The zone is to the immediate west of the orogenic belt and includes the rocks in the Hudson Valley and the Champlain lowland. The degree of deformation is very slight but increases to the east.

A north-south trending belt of metamorphosed Lower Paleozoic carbonate rocks forms the next zone, termed the Middlebury-St. Albans Synclinoria. The rocks correlate lithologically and stratigraphically

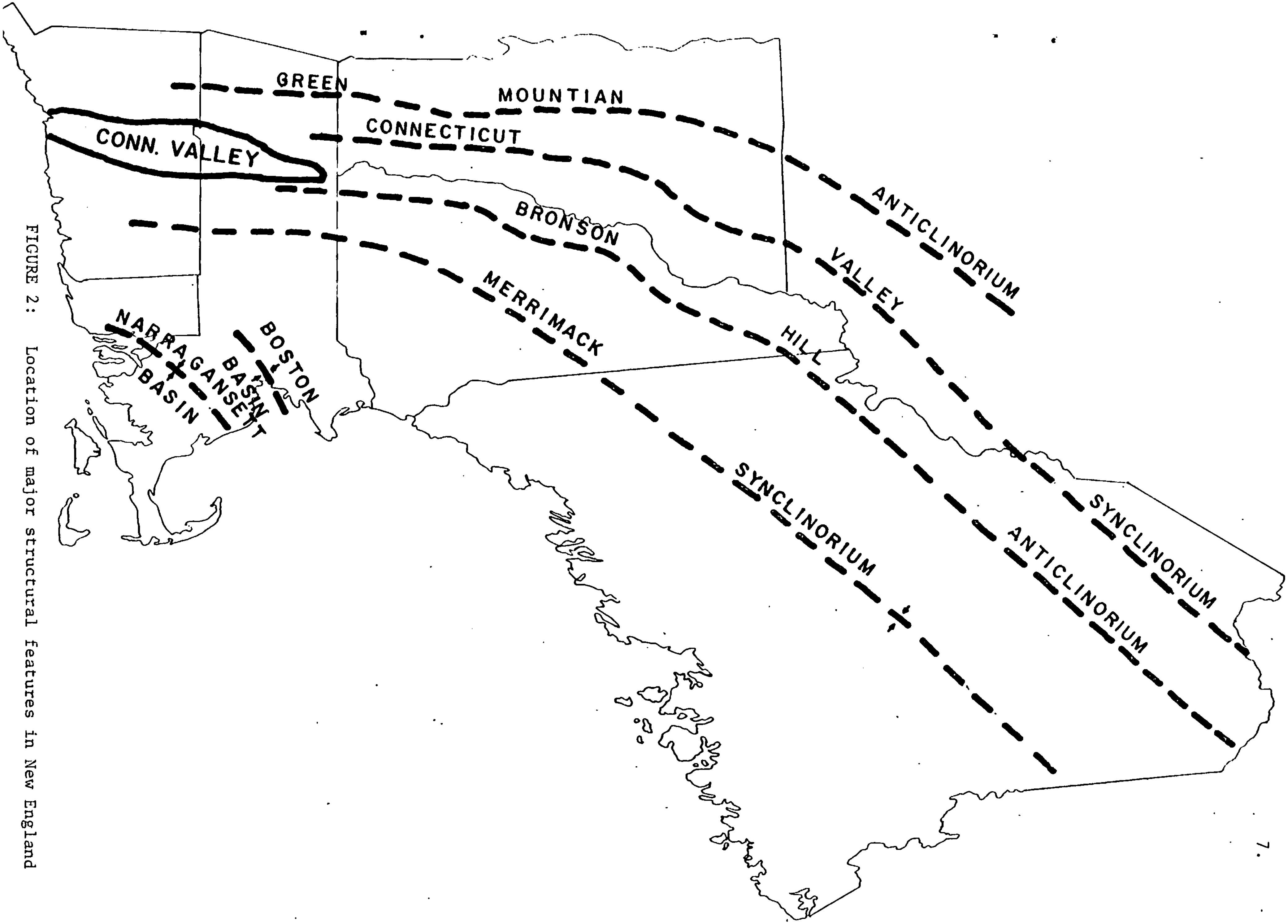

FIGURE 2: Location of major structural features in New England

with those of the foreland. They have, however, undergone two periods of deformation (the Taconic and Acadian orogenies). To the south the rocks are folded recumbently. The degree of folding diminishes northward and in western Massachusetts and Vermont the rocks are broken by thrust faults (Plate I). Within this belt of folded and faulted rocks is a zone of allochthones that slid into place from the east. They represent a facies that is intermediate between the platform sequence of the foreland and volcanic-bearing eugeosynclinal rocks. During Middle Ordovician time these masses slid into their present position as submarine "sheets", and are composed of rocks that range in age from Cambrian to Middle Ordovician.

The next zone eastward is dominated by large massifs of Precambrian rocks. In the New England region they are the Green Mountain massif (Vermont) the Berkshire massif (Massachusetts) and the Housatonic and New Milford massifs (Connecticut). They are the cores of large anticlinoria, the limits of which extend beyond the exposures of the Precambrian rocks.

The next zone to the east of the massifs consists of eugeosynclinal Paleozoic rocks that are intensely sheared, folded and metamorphosed to varying degrees. These comprise the western limb of the Connecticut Valley-Gaspe synclinorium. In New England this zone can be subdivided into two subzones. The western subzone consists of a homoclinal sequence dipping eastward off the massifs. The eastern subzone consists of domes superimposed upon isoclinal and possible recumbent folds. Ultramafic rocks are associated with both subzones.

The same eugeosynclinal sequence of rocks is exposed in the next zone, the Bronson Hill Anticlinorium, but here the structure consists of a series of knappes with a second line of gneiss domes superimposed on the nappes. The domes extend from northwestern New Hampshire to Long Island Sound.

The Merrimack Synclinorium comprises the next zone. It extends from northern Maine through central New Hampshire into eastern Massachusetts and Connecticut. Stratigraphically, rocks of this zone correspond to those in the Connecticut Valley-Gaspe Synclinorium from which they are separated by the gneiss domes of the Bronson Hill Anticlinorium.

The coastal belt is composed of a heterogeneity of eugeosynclinal rocks containing a large volume of volcanic and nonmarine rocks. These are probably of Ordovician, Silurian and Early Devonian age. There are also rocks of possible Precambrian age in southwestern New England.

Superimposed on these zones of pre-Arcadian rocks are two sequences of younger non-marine rocks, namely the Pennsylvanian age Narragansett and Boston basins and the Triassic-Jurassic age basin of the Connecticut River Valley. Both of these sequences probably covered most of New England at the time of deposition but have subsequently been removed by erosion.

The zones outlined above, with the exception of the Triassic-Jurassic basin, have been variously affected by one or more orogenies since the beginning of Paleozoic time, and evidence of additional orogenic events can be found in the Precambrian rocks. The Paleozoic orogenic events provide a useful reference for gross division of the stratigraphic column as used on the geologic map (Plate I).

The Taconic orogeny affected rocks of Cambrian and Ordovician age, so rocks of those ages are grouped as one unit on the geologic map.

This orogeny was apparently long lived, beginning in isolated localities in the Middle Ordovician and may include some events that occurred as late as Late Silurian time. The time between the Taconic and Acadian orogenies is represented by the deposition of Silurian to Middle Devonian rocks in New England. The Acadian orogeny had far greater affect on New England than either the Taconic or the later Appalachian orogenies, producing a higher grade of metamorphism and a large volume of plutonic rocks, which persisted from preorogenic to postorogenic time. It was also responsible for the formation of the synclinoria and anticlinoria and the formation of most of the nappes. The Appalachian orogeny affected the late Paleozoic rocks of eastern Massachusetts and Rhode Island.

The Triassic-Jurassic detrital and volcanic rocks are confined to the partly fault-bounded basin in central Massachusetts and Connecticut, are unmetamorphosed and therefore truly post orogenic. Thus in New England the late tectonic events appear to be restricted to high-angle faulting accompanied by volcanism and the emplacement of the White Mountain Magma Series.

Bouger Gravity Anomalies in New England

The first gravity map of the region was prepared by Longwell (1943) and covered a portion of southern New England. It was followed by a map and report by Woolard (1948) covering most of New England. These, and subsequent more detailed investigations (Bean, 1953; Joyner, 1963; Bromery, 1967; Diment, 1968; Kane and Bromery, 1968; Kane, 1970) have been combined by Kane et al. (1972) to produce a Bouguer gravity map of the region. The gravity map accompanying this report (Plate III) is a modification of the map of Kane et al. (1972).

Negative gravity values are dominant throughout New England and exceed -70 milligals in northwestern Massachusetts, southeastern Vermont and central New Hampshire. Positive gravity values exceeding +40 milligals are located in southwestern Connecticut and in the Cape Ann region north of Boston (Plate III).

Gravity trends are mostly north-south in western and southern New England and shift to a northeasterly trend in the rest of the region becoming most pronounced in Maine. The diversity in trend correlates in a general way with lithology and structure (Plate I).

Regional gravity anomalies are considered to be the result of variation in crustal thickness (Kane et al., 1972). Local anomalies appear as a sharp steepening of gradients and local closure of isogals. In New England the best defined cause of local, steep anomalies are masses of plutonic rock, the most common being felsic plutons associated with gravity lows. The pile of sedimentary rock in the Narragansett and Boston Basins does not produce a gravity low, probably as a result of the low grade metamorphism that accompanied the Appalachian orogeny. Likewise, the thick pile of post-tectonic sediments in the Connecticut River Valley does not give any indication of there being an associated gravity low probably due to their thorough cementation (in part of section by iron carbonate and iron oxide) and the presence of lava flows.

The regional gravity field correlates well with major geologic features, with gravity highs overlying broad areas of uplift and the lows over broad areas of subsidence and deposition (Longwell, 1943; Woolard, 1943). Two of the regional lows occur over large felsic plutons, one being the White Mountains of central New Hampshire within the Merrimack Synclinorium and the other in extreme northeastern Vermont within the Connecticut Valley-Gaspe Synclinorium.

The correspondence between tectonic features and major gravity features is apparent on a large scale, but does not hold in detail as noted by Diment (1968). Note, for example, the offset of gravity and tectonic highs in extreme western Massachusetts. It would seem, therefore, that the regional anomalies are caused by major crustal or crust-mantle structures of considerable vertical extent that are sometimes masked by geologic features within the upper crust such as the multiple thrusting of thin crustal sheets in western New England.

The predominate regional features of the western part of New England are the positive linear gravity high and the adjacent gravity low to the west (Plate III). Diment (1968) concluded that the principal cause of the high is the relative uplift of dense lower crust material while the low results from the depression of less dense crustal material into the more dense mantle. The gravity field in extreme western New England shows a range in gravity values over the relatively short distance of 125 km from + 40 mgals in southwestern Connecticut to - 65 mgals along the New York-Massachusetts border. This is in sharp contrast to the range/distance relationship in the rest of New England.

Another regional gravity low is more subdued and narrower than that in extreme western New England and occurs along the southern Vermont-New Hampshire border and extends into central Massachusetts. This low corresponds well with the Bronson Hill Anticlinorium which is composed of mantled gneiss domes and nappes. While local gravity lows appear over the domes, the more extensive feature is probably the result of the presence of a broad band of low density felsic material at depth below the anticlinorium.

The regional trend of the gravity field in the eastern two thirds of New England is northeast and parallel to the principal trend of the Appalachians. The regional field diminishes northwestward from the Gulf of Maine to the Canadian border. In Maine the local variations in the gravity field are associated with differences in lithologies, except in southeastern Maine over rocks that lie within the sillimanite isograd. (Plate III). Local gravity lows with sharp closure occur over Devonian age plutons. The large, elongate gravity low in northern Maine along the International Boundary is associated with the lower Paleozoic rocks of the Connecticut Valley-Gaspe Synclinorium . In southwestern Maine, most of New Hampshire, eastern Massachusetts, eastern Connecticut and western Rhode Island there is little correspondence between gravity lows and the Devonian age plutons. This large area of New England contains rocks that have been metamorphosed to sillimanite grade. Thompson and Norton (1968) have concluded that rocks within the sillimanite isograd were buried to at least 20 km based on metamorphic mineral equilibria. Exposure of these rocks at the surface may well indicate that the deep erosion accompanying uplift has removed most of the Devonian age felsic plutons. The deep gravity lows over the White Mountains are caused by the plutons of Jurassic and younger age which postdate the metamorphic event.

There is also a notable correspondence between gravity lows and topographic highs over much of New England, suggesting that the highlands are isostatically balanced by low density masses at depth. A major exception is the gravity low associated with the Green Mountain-

Sutton Mountain anticlinorium and the gravity low just westward over the Lake Champlain lowland. Since both of these regions are underlain by masses of complexly overthrust sheets of rock it is presumed that the crust in this region possesses enough lateral strength so that the load imposed by the overthrust sheets (the anticlinorium) is supported by the underthrust sheet (the lowland).

Seismicity

The level of seismicity, and the accordingly varied earthquake intensity, varies greatly from place to place in the northeastern United States. Although the region does not lie in a belt of major seismic activity, many earthquakes have been recorded since arrival of the first European settlers, and one area, Moodus, Connecticut, was sacred to the Indians because of the numerous tremors occurring there. The largest recorded seismic event (estimated intensity of VIII) occurred off Cape Ann, Massachusetts in 1755. Currently about 30 to 40 earthquakes are recorded yearly in the New England region.

Within New England there are certain areas (Figure 3) of higher seismiscity which appear to have remained stable over the last 300 years according to available historical records (Hadley and Evine, 1974). Recent, more accurately measured earthquake epicenters (Figure 4) for the period from October 1975 to June 1978 (Chiburis et al., 1978) fall within those areas of higher seismic activity in central New Hampshire and southern New England. However, the rate of activity within the areas of higher historical seismicity has been varied. For example, the area around Boston and Cape Ann was active in the first half of the Eight-eenth Century but has been quiet in more recent times. (Compare Figures 3 and 4).

Sbar and Sykes (1973) discussed the concentration of epicenters between Boston and Ottawa, Canada and suggest that the epicenters form a seismic zone. While it appears that a clustering of epicenters forms a zone from the north end of Lake Champlain to Ottawa, extension to the southeast is far from certain. The area of north-trending clustering of epicenters in eastern New Hampshire and the low seismicity belt of Vermont and Western Massachusetts conform to the regional structural trend and cut across the proposed Boston-Ottawa seismic belt of Sbar and Sykes.

A number of different causes have been called upon to explain the seismic activity in New England. Isostatic adjustment following deglaciation, stress accumulations at the borders of bodies of mafic rock due to density contrasts, reservoir filling and faulting have all been suggested as the possible causes for the seismic activity. None of these suggested causes can fully explain the distribution pattern of New England earthquakes, however.

Isostatic rebound due to ice unloading is certainly possible for the cause of some of the events, but in two areas of high seismic activity along the Maine coast the crust is sinking. The largest concentration of mafic rocks in New England lies within the belt of low seismicity of Vermont. Earthquakes do appear to be spatially related to the Mesozoic calderas in New Hampshire. The filling of the large Quabbin Reservoir in central Massachusetts has not generated any noticeable change in the local seismic activity. Movement along fault segments is considered the most likely cause of the earthquakes. Fault plane solu-

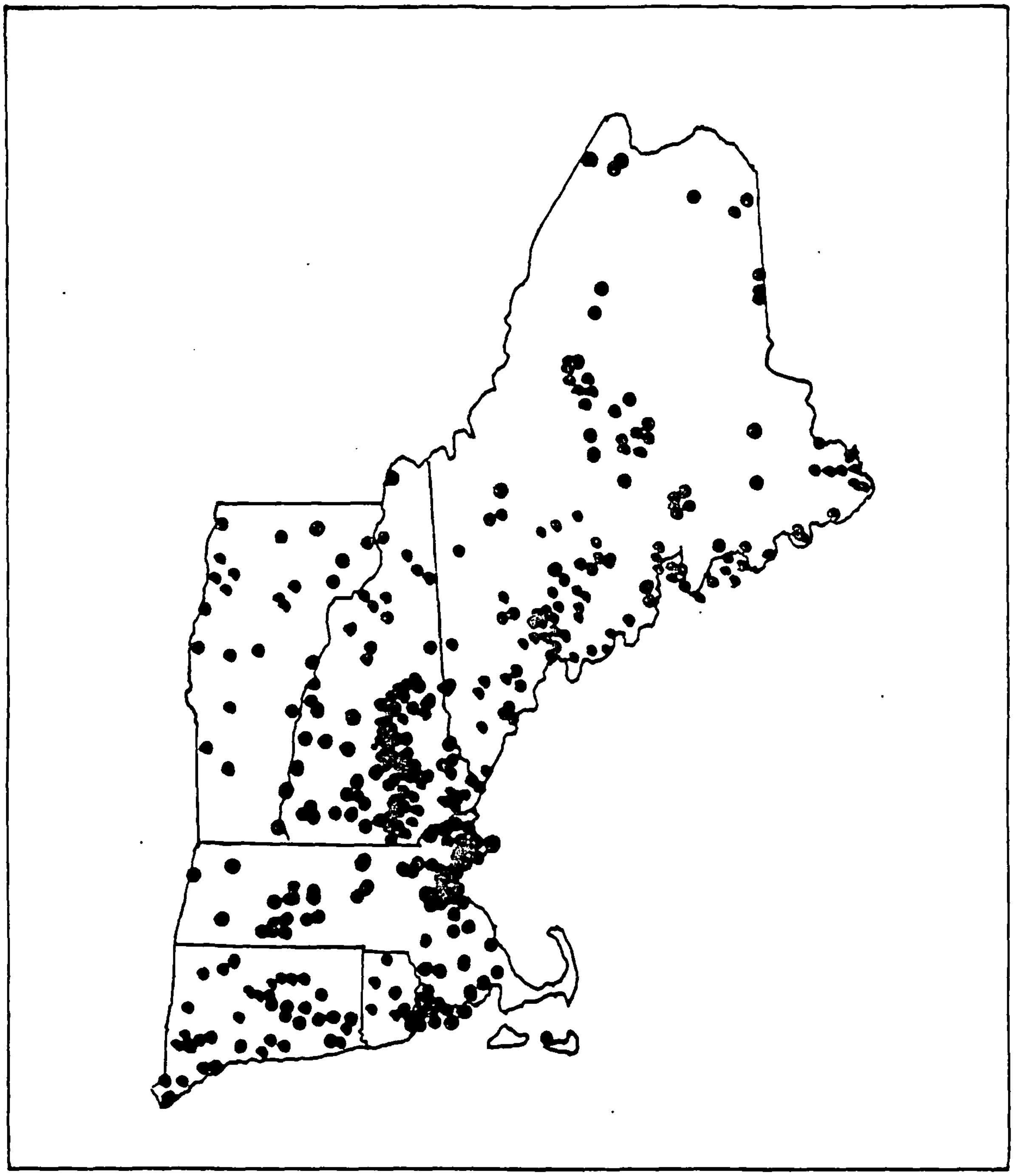

FIGURE 3: Recorded seismic events in New England from 1534 to 1977 (From Barosh et al., 1979)

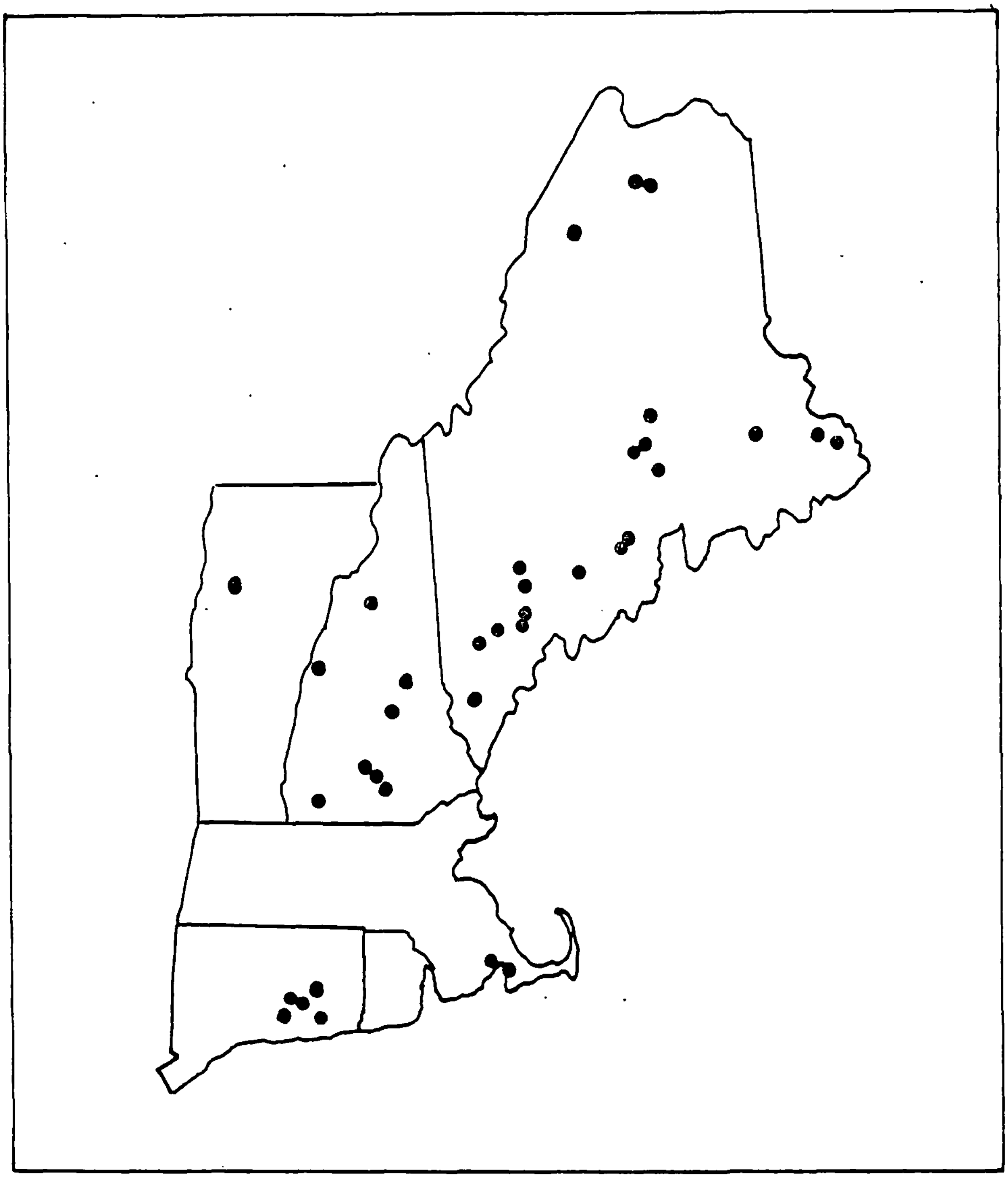

FIGURE 4: Recorded seismic events in New England for the period October 1975 to June 1978. (From Chiburis et al., 1978)

tions made from seismograph records from New England also suggest indirectly that the earthquakes originate on faults. However, there is no record of any surface fault movement accompanying a New England earthquake and nowhere in the literature is there any mention of an active fault. Since detailed mapping in New England has only begun in the 1930's there is not enough information available to reveal a basic tectonic pattern. Eastern Massachusetts and Connecticut are now known to be highly faulted and the rest of southern New England is probably equally as faulted (Figure 5). As for northern New England there has been little detailed mapping, but where it has been completed suggests that faults are abundant. The present evidence suggests major northeast zones of faulting across New England, with north and northwest trends being less abundant.

Major problems arise when attempting to date faults or periods of faulting. Many of the mapped faults in New England are of a compressional nature and are of Paleozoic age (225 5o 600 .m.y.), which may have been selectively reactivated. Also, there are very few areas of Mesozoic (65 to 225 m.y.) rock and virtually no Tertiary (1.8 to 65 m.y.) rocks, and where they do exist they are mantled by glacial till. The age of faults that cut the Mesozoic rocks is unknown but must predate the Cretaceous peneplanation that affected all of New England.

It would appear that areas of high seismicity are associated with zones of known or probable faults, but not with the zones of Paleozoic age compressional faults found in western New England. Zones of Mesozoic age high angle extensional faults are in some causes areas of high seismicity: the Champlain lowland, the southern Connecticut River Valley, the Narragansett Bay area, and the White Mountains of New Hampshire.

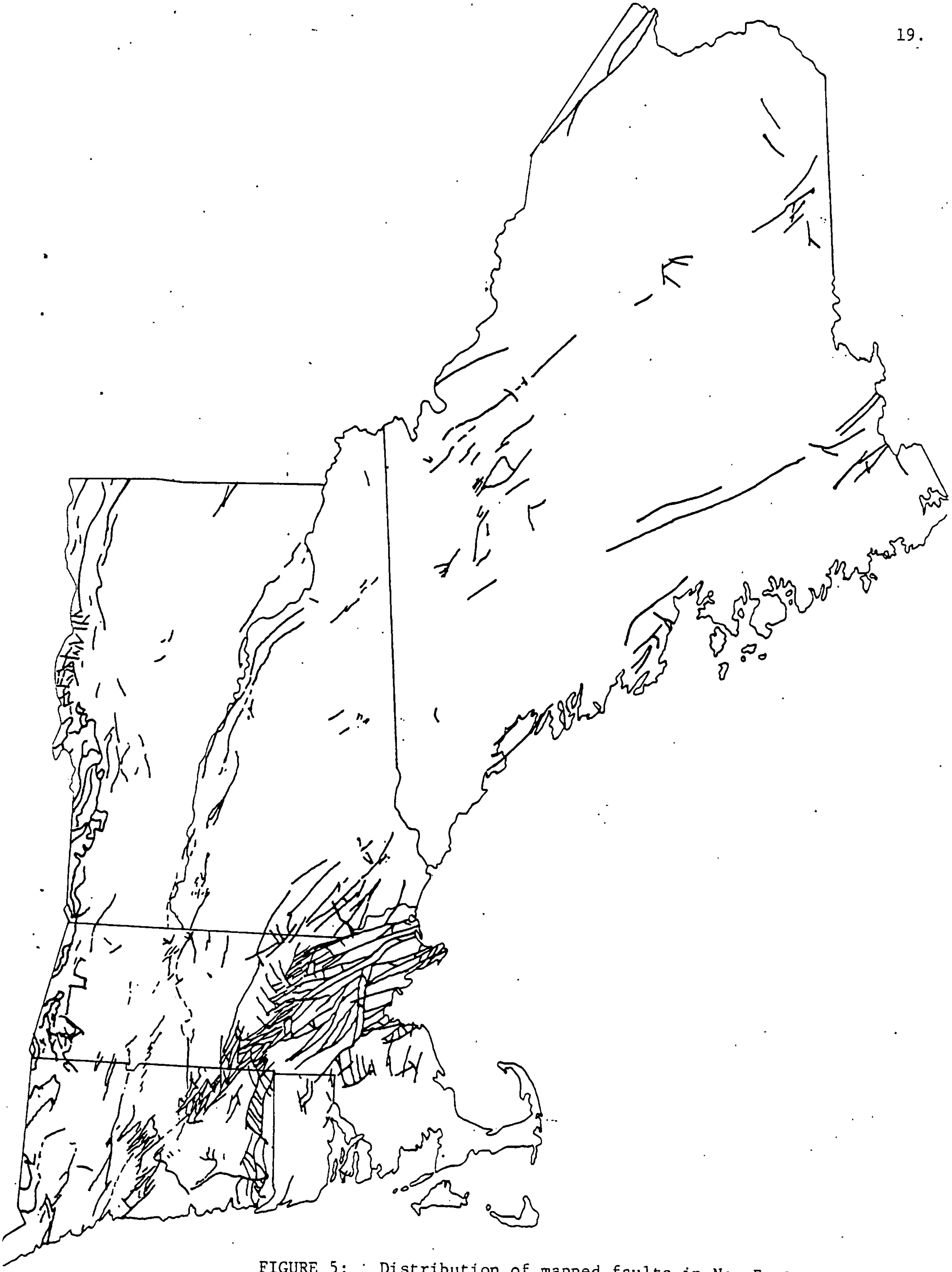

FIGURE 5: Distribution of mapped faults in New England

Except for seismic events in and near the White Mountains, the active areas of the New England region that have been instrumentally recorded occur in lowlands, bays, and major river valleys. These geomorphic features are directly related to the geology of the region. The lowlands are underlain by weak or soft rocks or have formed by extensional faulting and subsidence. Historic earthquake activity in New England therefore may be related to extensional faulting and may indicate minor rifting (Barosh, 1979).

Lineament Patterns in New England

The Mesozoic basins of Connecticut were studied by Hobbs and the first lineament maps were prepared in 1901, 1904, and 1911. He was among the first to recognize the existence of regional topographic lineaments. This pioneering work drew much attention and disbelief. More recently D. U. Wise and his students at the University of Massachusetts, Amherst, have been conducting fault, fracture and lineament studies in New England, particularly in western Massachusetts and Connecticut.

Wise (1976) noted that throughout New England the most pronounced linears are oriented N20E, N25W and N70E, of which the N25W set is the most pervasive. These linears cross all major tectonic boundaries in New England and hence must post-date the Paleozoic metamorphic events and the Late Paleozoic to Middle Mesozoic basin and caldera formation.

Comparison of the linear trends (Figure 6) and the faults of the region (Figure 5) clearly shows that the topographic linears are not great fault lines. However, Truesdell and Wise (1975) show that the linear trends correlate with small (up to a few meters displacement) fault orientations in a restricted area of western Massachusetts. Whether this correlation holds throughout all of New England is unknown at this time.

Wise (1976) interprets the linears in New England as beginning as incipient faults of a few tens to a few hundreds of kilometers of length following regional stress trajectories. They may become small faults, fault zones or zones of more intense development of joints. In the case of joint concentrations the joints need not parallel the zone itself, but merely be more intensely concentrated within the zone. Once formed these linears will maintain their existence, even penetrating sedimentary cover, by concentrating along them tidal strains, younger tectonic strains or the effects of propogation of seismic waves. At the surface the zone, be it fractured or faulted, provides easy access for ground water and deeper weathering to allow etching and preservation as elements of the topography.

Heat Flow

To date there have been seventeen heat flow measurements completed

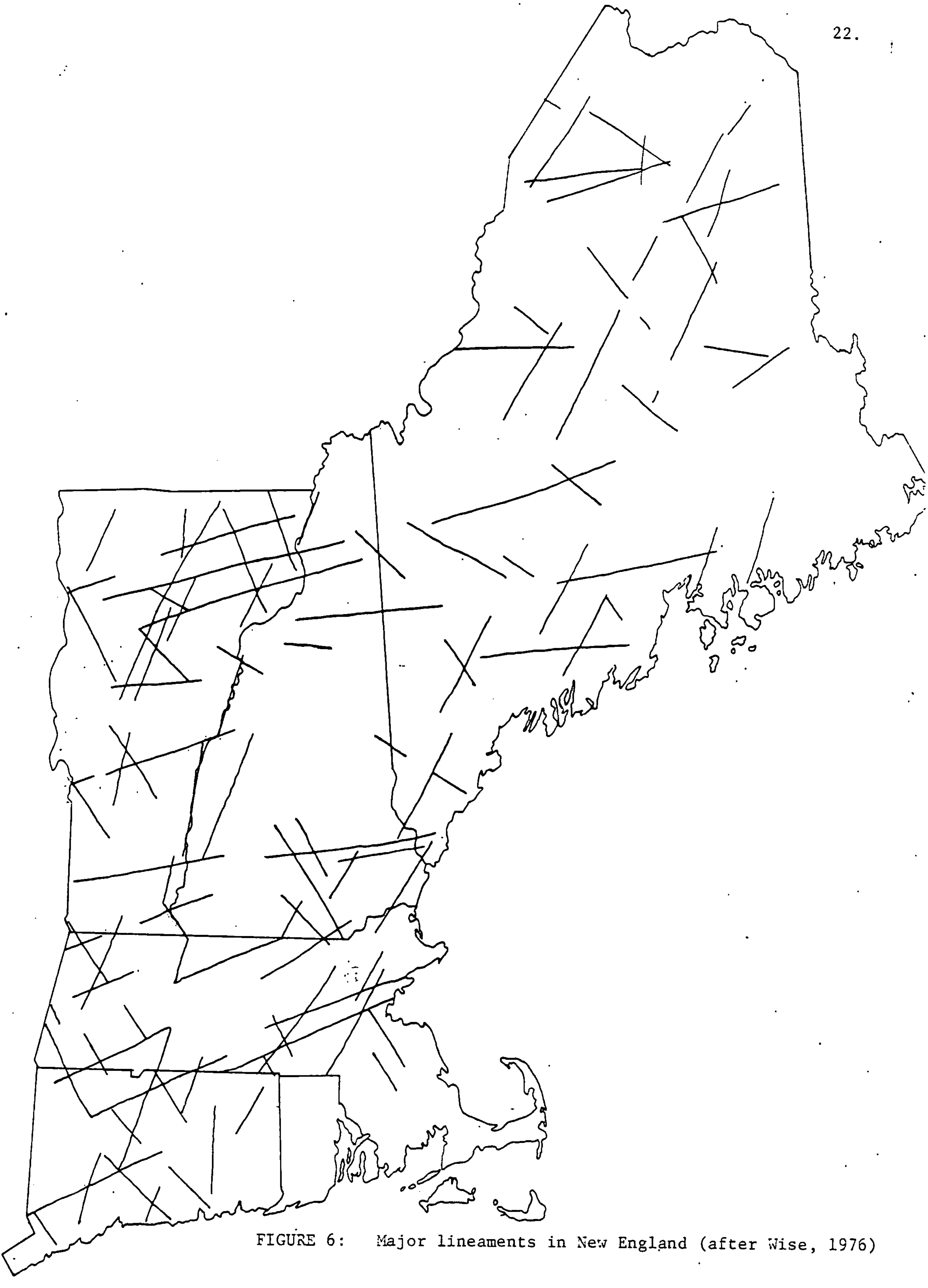

FIGURE 6: Major lineaments in New England (after Wise, 1976)

within the New England States. A detailed discussion of the thermal history is contained in Birch et al. (1968). The locations of the heat flow sites are given in Table 1 and Figure 7. The geologic distribution of the sites shows that the majority have been confined to Paleozoic-Mesozoic plutonic rocks in New Hampshire (eight), Massachusetts (two) and Maine (two). The three sites in Vermont are located in the Precambrian core of the Green Mountain anticlinorium. Of the twelve sites positioned in plutonic rocks three are located in the highly radioactive Conway granite (185 m.y.) of the White Mountain Magma Series, and the remainder in New England rocks of the New Hampshire Magma Series (360 m.y.). The highest heat flow values (Q) in New England are found in the Conway granite and the lowest in the Precambrian rocks of Vermont.

Since the bulk of the heat flow determinations in New England have been made in New Hampshire from rock of Devonian age or younger, Birch et al. (1968) have postulated a thermal history for New England (i.e., New Hampshire) beginning with Lower Devonian time. At that time there already existed in New Hampshire about 10 km of Ordovician and Silurian sediments deposited over a span of 100 m.y. Starting in Devonian time the rate of deposition increased and 15 km or more of deposits accumulated over a span of 50 m.y., which was followed by deformation, uplift and intrusion of the New Hampshire Magma Series comprising the Acadian orogeny. Erosion and uplift continued throughout the rest of Paleozoic time. During Triassic time another period of volcanism began in New England accompanied by the emplacement of the White Mountain Magma Series of which the Conway Granite represents the final phase. Since that time New England has been subject of slow uplift and erosion with a minor interruption during the Pleistocene glacial advance.

TABLE 1

HEAT FLOW IN NEW ENGLAND

LOCATION	Heat Flow Microcals/cm^2 sec. Topographic Corrected	 Geologic Corrected
Blue Hill, ME	1.44	1.30
Casco, ME	1.80	1.63
Brewster, MA	1.16	1.29
Cambridge, MA	1.20	1.20
Chelmsford, MA	1.63	1.48
Millers Falls, MA	1.67	1.51
Bradford, NH	1.59	1.44
Concord, NH	1.73	1.57
Durham, NH	1.08	0.98
Fitzwilliam, NH	1.63	1.48
Kancamagus, NH	2.27	2.13
North Conway, NH	1.89	1.95
North Haverhill, NH	1.34	1.21
Waterville, NH	2.15	2.21

From Birch et al., 1968

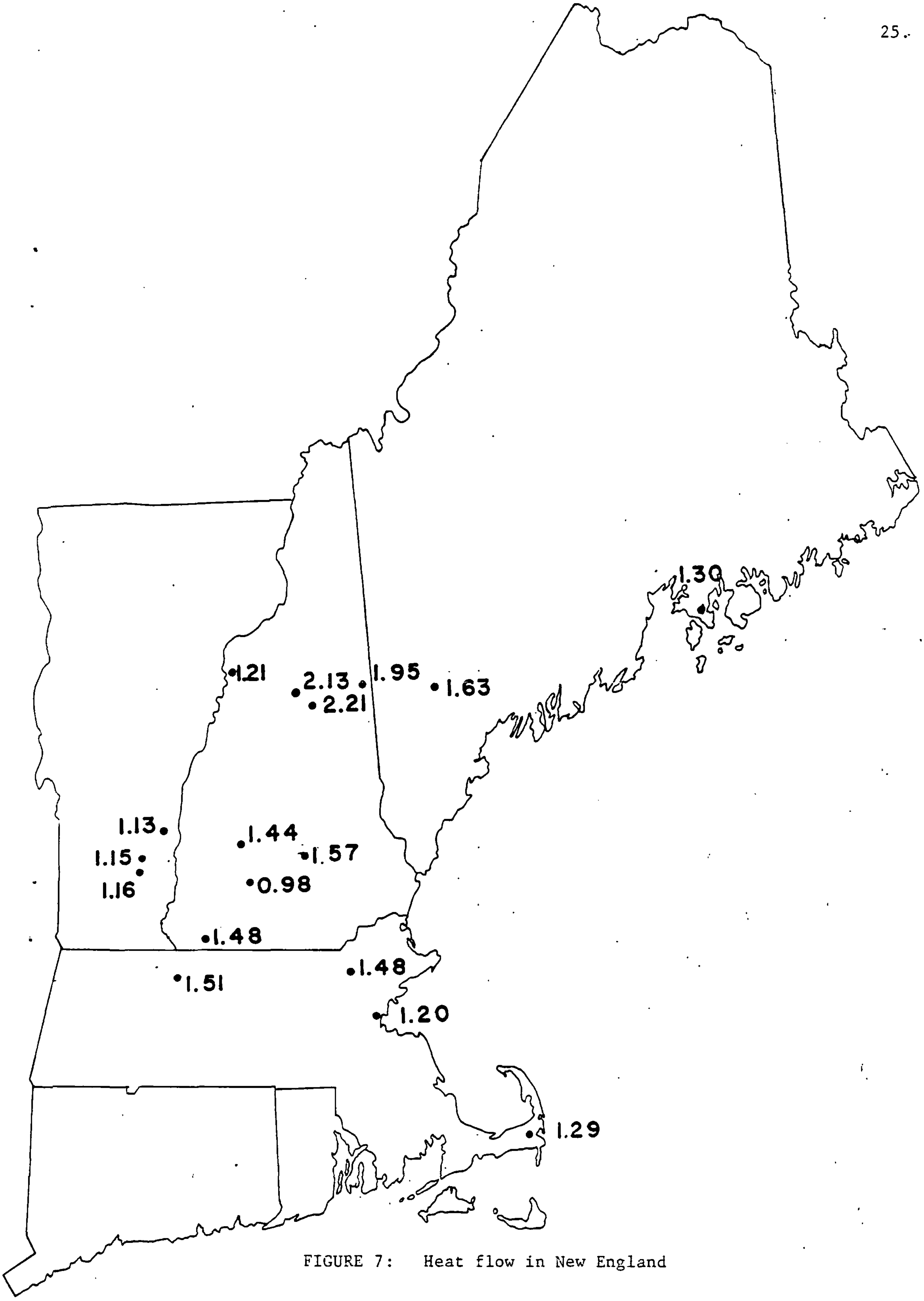

FIGURE 7: Heat flow in New England

The net effects of varying rates of sedimentation, intensity of metamorphism and the depths of emplacement of plutonic rocks (15 km for the New Hampshire Series versus 6 km for the Conway Granite) and erosion rates have altered the normal heat flow regime such that corrections have to be applied. However the magnitude of the "geological" corrections is not great (Table 1).

The correction for erosion effects are best applied to sites in New Hampshire, namely Bradford, Concord, Fitzwilliam and also Chelmsford, Massachusetts and Casco, Maine, all of which lie within the belt of deep Paleozoic sedimentation. Less certain is the application of erosion-rate correction at Blue Hill, Maine, North Haverhill and Durham, New Hampshire, and Millers Falls, Massachusetts. However, for the above Birch et al. (1968) have calculated a mean geothermal gradient of 18.3°C/km from averaged measured gradients with a mean value of 20.2°C/km thus providing a reduction of 9.4% in the topographically corrected values for heat flow. For the heat flow values calculated for the sites in the White Mountain Magma Series (North Conway, Kancamagus and Waterville, New Hampshire) a correction factor of 1.6°/km was subtracted from the gradients. The same correction factor has been applied to the gradients measured at the three sites in Precambrian rocks in Vermont. In the case of the site at Brewster, Massachusetts on Cape Cod, a 10% upward correction was applied to take into consideration the deposition of about 100 meters of sand following the retreat of the Pleistocene glaciers.

M. P. Billings (1964) prepared a map (unpublished) in which he contoured "equivalent uranium" (eU) for Maine, New Hampshire and Vermont. The quantity eU was used to show the gamma activity from uranium, thorium and potassium in terms of the amount of uranium and daughter products in equilibrium required to produce the same effect. Although the formula used by Billings ($eU_{gamma} = U + 0.48Th + 3K$; U and Th in ppm, K in percent) is different from that to calculate equivalent uranium for heat generation ($eU_{thermal} = U + 0.27Th + 0.37K$), eU_{gamma} is roughly proportional to A, the rate of heat generation per cm^3. Therefore a correlation between heat flow (Q) and A also provides a correlation between heat flow and eU. Birch et al. (1968) noted a strong correlation between heat flow values and eU contours of Billings and concluded that contours of bedrock eU can be converted to heat flow contours with errors on the order of 0.2 microcal/cm^2 sec for the region.

Heat flow values for the Precambrian anorthosite in the Adirondack Mountains of New York average 0.8 microcal/cm^2 sec and this value is attributed to be the contribution of the lower crust and mantle to the flux. Subtracting that amount from the calculated heat flow in the Conway Granite leaves 1.2 microcal/cm^2 sec to be supplied by radioactive decay in the granite. Assuming even distribution of radioactive elements in the granite, Billings et al. (1968) calculate upper limit of the thickness of the Conway Granite to be 6 km, which is reasonable agreement with an estimate of 4.5 km thickness required to explain the gravity low (Joyner, 1963).

New England Ground Water Resources

Most of the ground water resources in New England lie in the region defined by the U. S. Water Resources council as the Glaciated Appalachians region, the exception being Nantucket, Martha's Vineyard and Cape Cod which lie in the Coastal Plain ground water region. In the region average annual temperature ranges from 3.3°C (38°F) in northern Maine to 10°C (50°F) in Connecticut, Rhode Island and southeastern Massachusetts. The annual average precipitation ranges from 1000 mm (40 in.) in the north to 1140 mm (45 in.) in the south. By 1975 ground water constituted twenty-three percent of the total fresh water withdrawals in the nation. In New England ground water contributed twelve percent of the total fresh water withdrawals.

Most of the New England region is underlain by impermeable crystalline rocks from which small amounts of ground water are retrieved for domestic and livestock supplies from fracture zones. Sedimentary rocks in the region consist of carbonate and clastic sequences. The carbonate rocks, consisting of limestone, dolomite and calcareous shales, occur in the Hoosatonic River Valley in western Massachusetts and Connecticut and in the Aroostock Valley in northern Maine. Wells drilled in carbonate rocks can produce substantial ground water supplies if large solution openings are penetrated in the zone of saturation. The non-carbonate sedimentary rocks are mostly confined to the Connecticut River Valley lowland and consist of shale, sandstone, arkose, conglomerate and interbedded basalts. The sedimentary rocks yield small to moderate supplies, some wells providing as much as 19L/s (300 gal/min).

In parts of New England low grade metamorphosed sedimentary rocks yield small to moderate supplies of water. Rocks of this type, consisting of metaconglomerate, argillite, phyllite, slate and marble, occur widely in Maine, in western Massachusetts and western Connecticut, northwest of Boston, and in the Boston and Narragansett Basins of eastern and southeastern Massachusetts and southeastern Rhode Island. In a few places supplies up to 32L/s (500 gal/min) are obtained from strongly fractured zones.

The most productive sources of ground water in New England are unconsolidated sediments,which consist of glacial and glaciofluvial deposits and the reworked glacial deposits in present day river and stream valleys, termed watercourse aquifers. Thomas (1952) defines watercourses as hydrologic units that include both surface water of a river channel and the ground water in the alluvium that forms the flood plain. The glacial deposits in New England consist mostly of stratified drift (sand and gravel) with moderate to high permeability. The watercourse aquifers provide the highest yields of ground water with some individual wells yielding up to 125L/s (2000 gal/min) due to hydraulic continuity between the river and surrounding porous and permeable glacial outwash that underlies the flood plain. With the retreat of the glacial ice front northward at the close of Pleistocene time large volumes of melt water produced deep river channels, which were later filled with alluvium. With the reduction in discharge and subsequent land uplift that accompanied the glacial retreat, many of these river courses have been greatly reduced in size and some completely abandoned, and remain today as deep valleys filled with alluvium. They have an extent, thickness and permeability far greater than present streams could possibly produce, and some no longer form any part of the present drainage system. However, the opportunity for recharge may, in many cases, be limited to direct infiltration from precipitation and the perennial yield is likely to be less than that of the watercourse aquifers.

The contribution of ground water to the total discharge of a river is the <u>base flow</u>. The mean stream flow (Sinnott, 1982) for the New England Region has been determined to be about 258 x $10^2 m^3$/d

(68 x 10^9 gal/d). Using a conservative estimate of a base flow of forty percent of the mean stream flow of the entire region the average total yield of groundwater to discharge is about 102 x $10^2 m^3 d$/ (27 x 10^9 gal/d). The large volume of lateral discharge of ground water in glacial till and alluvium that mantles all of New England therefore will in most cases dilute and mask any heated water that might be discharged at the bedrock surface.

Use of Ground water as an Energy Source

Technology Property Associates (TPA) of Burlington, Massachusetts, has constructed an office building that uses ground water for both heating and cooling purposes as a backup for the primary solar energy system. The system is maintained and operated by Aerospace Systems, Incorporated which states that although the system was designed as a backup, the water-to-water heat pump is able to extract 3 1/2 times more useable energy from water than an electrical resistance heating element could produce, and could be the primary energy source in a properly designed building in New England.

The extraction of energy from water courses has been proposed for the City of Stamford, Connecticut, through which the Rippowan River flows. The proposer, Wormser Scientific Corporation of Stamford, notes that the ground water conditions in Stamford are well known as the result of over 500 borings taken in conjunction with planning and construction of a 130 acre urban renewal project and the earlier construction of Interstate Highway I-95.

Two main shallow aquifers traverse Stamford in a N-S direction and one of these is rated as being capable of supplying 2.8 million gallons per day on average for consumptive use, i.e, without any return of the water to the aquifer. The water temperature varies between 10°C (50°F) and 11°C (52°F) annually. The proposer (personal communication, Wormser Scientific Corporation) plans to extract water from the aquifer to cool structures and return this water, now warmer by 5° to 8°C by their calculations, to the aquifer at a different location. It is this system that currently is in use in the TPA structure. They state that the direct distribution aquifer cooling system uses about 10% of the electrical energy requirements needed to operate a conventional air conditioning cooling system. Heat pumps in the heating mode extract heat from ground water at 10°C and amplify it using a compression refrigeration cycle to around 37°C (100°F) for heating purposes. The reinjected water will be cooled to around 5°C, but the amount of water removed and reinjected into the aquifer will be a small fraction of the total volume available.

The very large volume of ground water available in New England makes this resource a potential source of energy using water interface heat pumps.

Thermal Springs in New England

Seepage springs are abundant in New England, especially at the contact of glacial till and bedrock. There are some springs, however, that are fracture controlled and apparently circulate meteoric water to sufficient depth to become heated by the normal geothermal gradient.

A search of the literature, particularly that of the nineteenth century, was conducted to establish the existence of any possibly warm springs. In a report on the geology of Vermont, Adams (1848) makes note of Morgan Spring in the center of Bennington as possibly being a warm spring. Stearns et al. (1937) report that the spring was listed again in 1934 as a thermal spring with a temperature of 11.7°C (53°F) which is 4°C above the mean annual temperature. The spring is not listed by Waring (1965) nor Berry et al. (1980) and a visit to the area failed to locate the spring.

Daubney (1839) reported another slightly warm spring at Cannan, Vermont, but no subsequent listing could be found, nor could the spring be located.

Hitchcock (1861, p. 174) in a report on the geology of Vermont noted a number of springs producing calcareous deposits. When visited these proved to be normal ground water springs in a carbonate terraine.

Lebanon Springs - Sand Springs Area of New York and Massachusetts

Both Lebanon Spring in eastern New York and Sand Spring in Williamstown, Massachusetts have somewhat elevated temperatures that have been utilized for a number of purposes over the past decades. Lebanon Spring is located in the northwest corner of the Pittsfield west 7 1/2 quadrangle and lies about 17 miles south-southeast of Sand Springs.

At Lebanon Spring a 400 room hotel named Columbia Hall was built in 1794. The structure was removed in 1928 ironically because of the high cost of conventional heating. The Rutland Railroad laid a mile long pipe line from the spring in 1906 for recharging locomotive boilers. After abandonment of the railroad about thirty local families tied into the line and use the warm waters for domestic purposes. At the present time there is no use of the spring waters related to elevated temperature.

Sand Spring has been in use since pre-Colonial times. Carlin (1972) states that the spring was used by area Indian tribes as a landmark and campground for hunting and war parties, lying near the intersection of a north-south trail and the Mohawk Trail. A health spa, Graylock Hall, containing 26 large baths and 6 sunken bathing pools was built in the 1880's. A bottling works was added in 1893 and ceased production in 1972.

The most recent geological study of the Lebanon and Sand Springs by Dunn Geoscience Corporation for New York State Energy Research and Development Authority (1981) states that the thermal waters issue from Cambro-Ordovician rocks involved in the thrust belt of western New England and eastern New York. They interpret the elevated water temperatures to be the result of deep ground water circulation along permeable zones created along thrust fault planes. In the case of Lebanon Springs, Cambrian age phyllites have been thrust westward over Ordovician dolomite, and the dolomite has been as a result tensionally fractured to provide permeability (Fig. 8). Since the geothermal gradients in the area do not appear to be high it is estimated that water circulation to about 1 km depth could account for the 22°C (72°F) measured at Lebanon Spring.

The thermal springs at Williamstown, Massachusetts, may occur in a slightly different geologic setting. The springs occur at three locations; each location forming the apices of a triangle approximately one mile distant from each other. Unfortunately the detailed bedrock geology is obscured by surficial materials at the point of issue for each spring. At Sand Spring itself the thermal water with a temperature of 24°C (76°F) flow may be along the contact of Cambrian quartzite thrust over Ordovician limestone (Fig. 8). The remaining two springs appear to issue from a

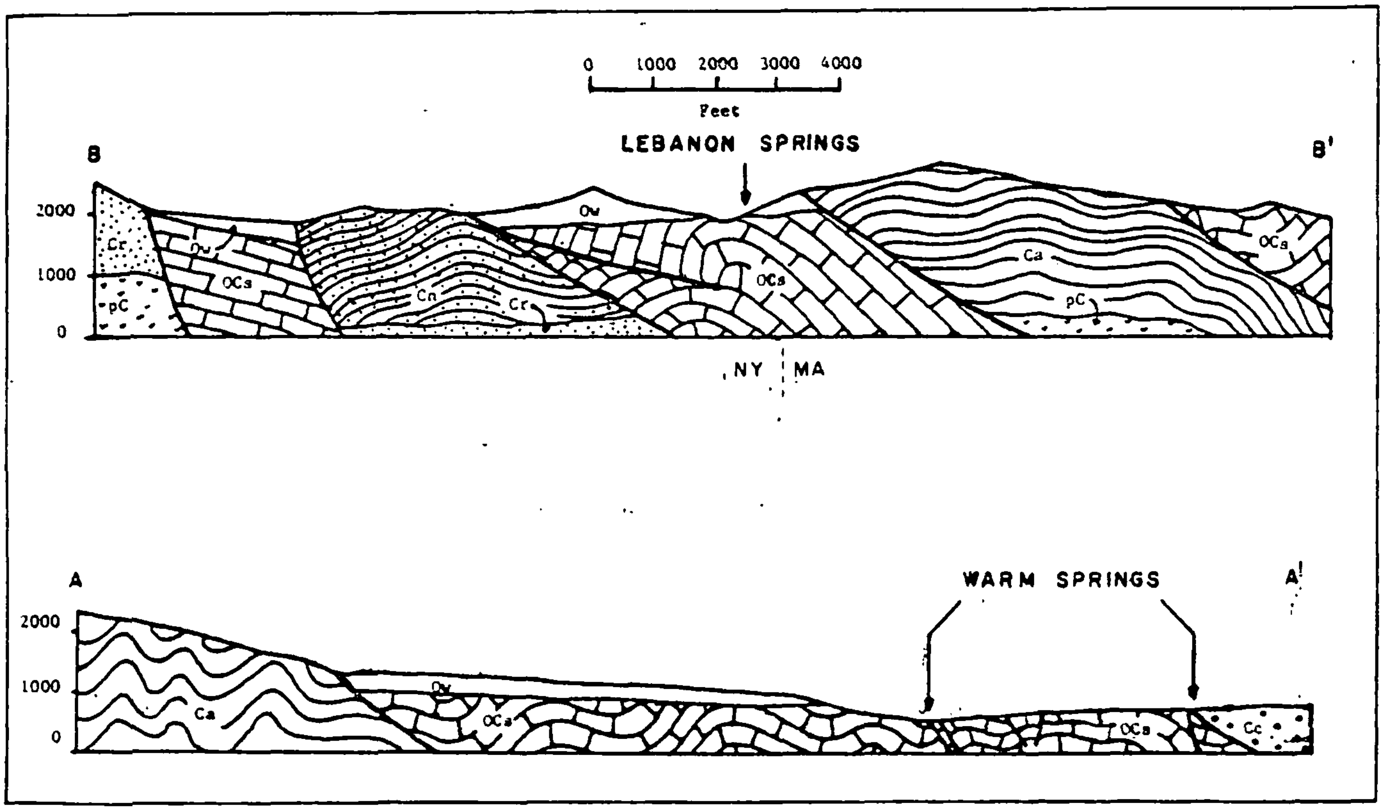

FIGURE 8: Geological cross sections in western Massachusetts. Section locations shown on Figure 9B. Section A-A' shows the warm springs at Williamstown, MA, are associated with high angle reverse faults involving the Cambro-Ordovician Stockbridge group (OCs) and the Cambrian Cheshire formation (Cc). Section B-B' shows the Lebanon Springs emerging at the contact of the Ordovician Wallomsac formation (Ow) and the Stockbridge group after ascending on the thrust fault about 1000' to the southeast. (Modified from NYSERDA Report 81-4 prepared by Dunn Geoscience Corporation).

fault zone within the Ordovician dolomite. The water temperatures were recorded as 19.5°C (67°F) for the northern and 20°C (68°F) for the southern spring. Since the geothermal gradients in the vicinity of Williamstown are not elevated it would appear that deep circulation of ground water is the source of the heated waters.

Hansen et al. (1974) have analyzed the waters from wells at Sand Springs (Table 2). The warm waters are represented by analyses S'2, S'2a and S'8. It is obvious that there exists a direct correlation between temperature and SiO_2 content, suggesting that the waters of Sand Spring probably attain a higher temperature at depth. The flow rate at the springs is approximately 24,000 gallons per hour (Waring, 1965).

The New York State Energy Research and Development Authority report (1981) prepared by Dunn Geoscience Corporation gives the results of a survey of water chemistry, temperature and measured gradients,which included a portion of western Massachusetts and southwestern Vermont. The silica contents and measured water temperatures at the surface are given in Table 3, and locations on Figure 9.

The feasibility of utilizing the thermal waters of Sand Spring for domestic heating purposes appear to be good. The water quality is excellent; the water temperature is approximately 14°C above that of normal ground water and the flow rate (400 gal/min) more than adequate.

Some geothermal gradients in western Massachusetts and southwestern Vermont are abnormally high and increase into eastern New York. The background geothermal gradient appears to fall in the range of 5 - 7°C/km. The abnormally high gradients (Figure 9, Table 4) form a north-northeast trending zone extending from Lebanon Springs New York to the vicinity of Pownal, Vermont, and range up to four times the

TABLE 2

CHEMICAL ANALYSES OF SPRINGS IN WILLIAMSTOWN, MASSACHUSETTS

Local Well #	S2	S2a	S3	S6	S7	S8	S9
Temp. °C	21.0	22.0	11.0	8.1	22.0	17.8	8.9
SiO_2 (mg/l)	13.0	12.0	0.5	4.2	12.0	7.2	0.6
Fe (ug/l)	20.0	20.0	10.0	--	20.0	20.0	10.0
Mn (ug/l)	0	0	0	--	0	0	0
Ca (mg/l)	21.0	23.0	24.0	18.0	25.0	46.0	36.0
Mg (mg/l)	11.0	8.8	4.2	3.0	8.9	11.0	11.0
Na (mg/l)	3.3	2.0	1.3	0.3	2.0	1.9	1.9
K (mg/l)	1.3	0.9	0.2	0.1	0.9	0.6	0.8
HCO_3 (mg/l)	116.0	118.0	84.0	68.0	114.0	177.0	154.0
CO_3 (mg/l)	0	0	0	0	0	0	0
SO_4 (mg/l)	8.6	8.1	7.5	6.0	8.1	11.0	6.5
Cl (mg/l)	2.0	1.0	0.4	0.1	1.3	0.8	0.6
F (mg/l)	0.1	0.1	0.2	0.0	0.1	0.1	0.2
NO_3 (mg/l)	0.4	1.0	1.0	4.2	0.4	0.7	1.1
pH	8.2	7.8	7.7	7.7	8.1	8.0	8.1

From Hansen et al., 1974

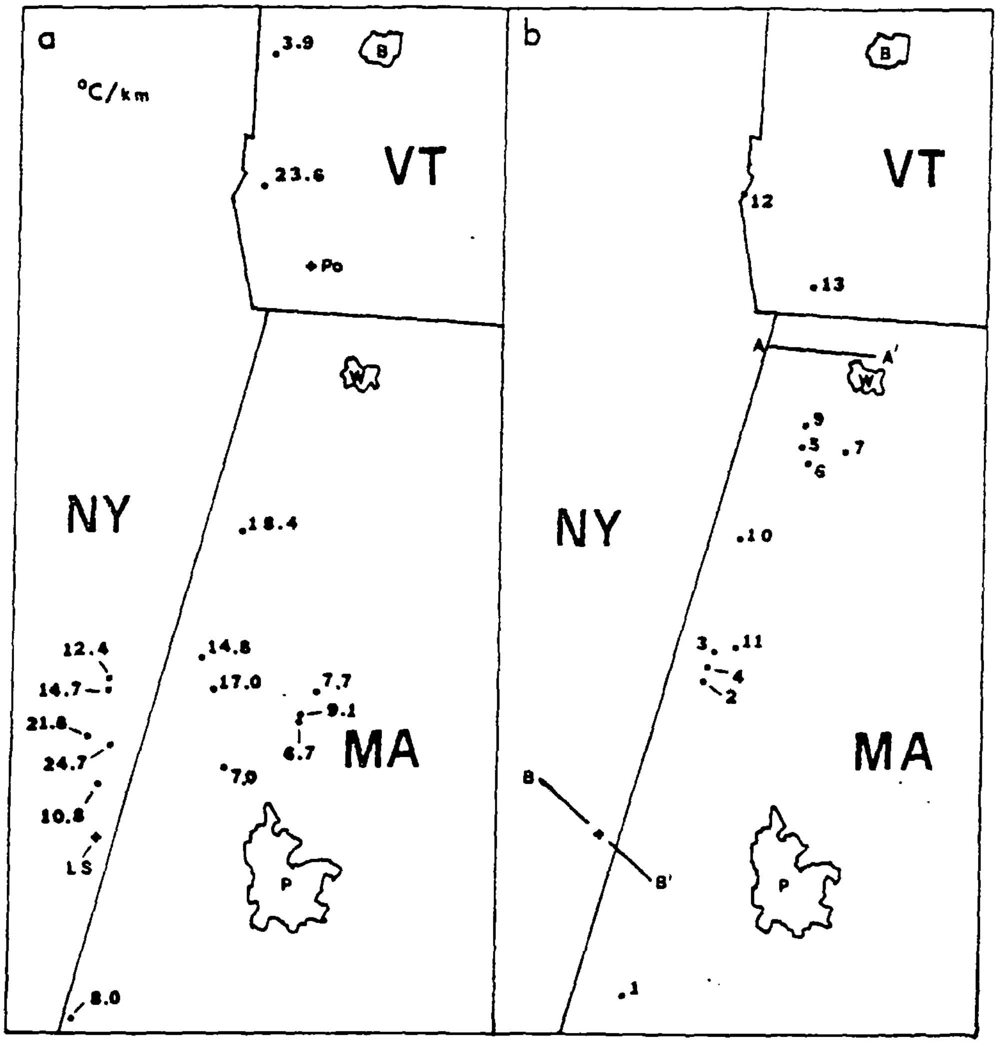

FIGURE 9: a) Geothermal gradients (°C/km) in western Massachusetts, New York and Vermont. Communities shown are: B = Burlington, VT., PO = Pownal, VT., W = Williamstown, MA, P = Pittsfield, MA, and LS = Lebanon Springs, NY.

b) Location of wells listed in Table 3. The cross-sections in Figure 8 are located near Williamstown (A-A') and Lebanon Springs (B-B'). (Modified from NYSERDA Report 81-4 prepared by Dunn Geoscience Corporation.)

TABLE 3

SILICA CONTENTS AND WATER TEMPERATURES

Western Massachusetts and S. W. Vermont

Sample Number	NAME	Silica ppm	T(^{o}C)	LOCATION
MASSACHUSETTS:				
1	Shyffer	5.9	7.2	Deerhill Rd., Richmond, MA.
2	Leab	5.6	11.9	Rt. 43, Hancock, MA.
3	Monette	5.7	11.8	Rt. 43, Hancock, MA.
4	Fenander	5.3		Rt. 43, Hancock, MA.
5	Locke	6.1	8.3	Oblong Road, Williamstown, MA.
6	Greylock H. S.	6.7		Williamstown, MA.
7	Mt. Hope Farm	6.3		Williamstown, MA.
8	Rhodes	5.5		Hancock Road, Williamstown, MA.
9	White	6.1		Oblong Road, Williamstown, MA.
10	Jericho Valley Motel	5.2		Rt. 43, Hancock, MA.
11	Hamilton	4.2		Hancock, MA.
VERMONT:				
12	Sheldon	6.5	10.3	Rt. 396, NY/VT border
13	Gen. Cable	9.2		Rt. 396, N. Pownal, VT.

TABLE 4

TEMPERATURE GRADIENTS

Eastern New York and Adjacent Vermont and Massachusetts

LOCATION	DEPTH (METERS)	GRADIENT (^{o}C/km)
Pownal, VT.	220	23.63
Hancock, MA.	140	14.82
Hancock, MA.	155	17.03
Rt. 43 & Rt. 22, Stephentown, N. Y.	145	14.72
Stephentown Center, N. Y.	185	21.60
Rt. 43, Hancock, MA.	130	18.36
Wyomack Road, South Stephentown, N. Y.	160	24.68
West Road, Lebanon Springs, N. Y.	80	10.83
Saltbox Farm Road, Hancock, MA.	190	7.72
Bailey Road, Hancock, MA.	260	9.06
Bailey Road, Hancock, MA.	125	6.73
Churchill Road, Pittsfield, MA.	160	7.01
Off Rt. 22, Stephentown, N. Y.	80	12.40
Vt. Route 9, Bennington, VT.	105	3.86
West Road, West Richmond, MA.	185	7.95

apparent normal gradient (from 6.7 to 23.6° C/km.). However no additional thermal springs and no wells pumping heated waters have been located.

New England Water Well Temperatures

Since most of the consumptive water supplies in New England are derived from surface storage reservoirs and the bulk of the ground water contribution to that supply is derived from unconsolidated glacial sediments, only a small fraction comes from wells driven to bedrock. Although the rocks of the region are highly fractured and faulted, water wells intersect only a minute fraction of these structures and therefore provide a very small sampling of the fluids possibly circulating within them.

Water temperatures from bedrock wells range from 6°C (41°F) at Presque Isle, Maine from a 94m (310') well to 19°C (67°F) at Somerset, Massachusetts, from a 457m (1500') well (Table 5). Most water temperatures fall below 13°C (55°F) and in Massachusetts, which contains the largest number of drilled wells, the average temperature is 11.4°C (Table 6).

Specific Regions of Initial Interest

Based upon geological and geophysical studies certain areas in New England were considered to have the highest potential for the possible existence of hydrothermal geothermal resources. These included the White Mountains region of central New Hampshire, the Narragansett Basin of Massachusetts and Rhode Island, the Connecticut River Valley extending from Connecticut north into Vermont, and the overthrust belt of western Massa-

TABLE 5

Partial Chemical Analyses in ppm of Waters from Selected Wells in New England Bedrock

Location	Depth (m)	Source Rock	T(°C)	SiO_2	Ca	Mg	Na	K
MASSACHUSETTS:								
Abington	15	Gneiss	7.2	9.6	12	3.3	8.8	1.2
Brockton	31	Gneiss	7.8	11	22	5.3	4.9	.6
Duxbury	33	Gneiss	8.9	5.3	8.4	2.0	4.1	1.4
E. Bridgewater	25	Gneiss	11.1	17	16	8.4	8.3	1.0
Taunton	64	Argillite	11.7	24	15	2.5	14.0	1.1
Mattapoisett	?	Argillite	9.4	25	37	9.1	11.0	3.7
Lynnfield	180	Schist	7.8	17	14	5.0	7.3	1.2
Wilmington	125	Schist	9.5	11	23	5.8	13.1	1.9
Middleborough	?	?	9.4	11	3.2	2.0	5.8	.5
Adams	146	Quartzite	10.8	17	6.6	1.4	1.1	.3
Windsor	45	Gneiss	9.7	13	16	6.2	5.3	.7
Charlemont	77	Gneiss	9.4	15	9	5.7	4.2	.4
Goshen	32	Gneiss	9.5	12	10	6.8	5.0	.6
Bernardston	?	Gneiss	9.8	17	13	7.2	6.1	1.1
Hardwick	61	Gneiss	10.1	21	11	6.2	7.3	.9
Belchertown	56	Gneiss	10.6	18	14	5.2	4.1	.6
Easthampton	143	Triassic	12.3	21	29	2.6	4.2	.5
Florence	92	Triassic	11.9	25	31	4.3	3.0	.5
Hatfield	?	Triassic	12.6	31	27	5.2	4.6	.7
Barre	?	Gneiss	10.1	14	7	5.8	3.6	1.1
Boxford	?	Gneiss	10.0	8	17	4.8	8.0	1.8
Georgetown	?	Gneiss	10.0	15	22	9.0	14.0	1.5
Newbury	37	Gneiss	11.1	13	13	4.4	59.0	2.2
Egermont	30	Limestone	10.0	6.9	0.2	0.1	103.0	0.2
Washington	15	Gneiss	13.3	12	22	7.4	2.5	4.9
Williamstown	113	Limestone	8.9	6.6	23	13	1.1	0.7
Gill	40	Sandstone	13.3	11.0	24	15	4.3	1.1
Chicopee	34	Shale	12.8	15.	96	19	18	1.5

Location	Depth (m)	Source Rock	T(°C)	SiO_2	Ca	Mg	Na	K
CONNECTICUT:								
Granby	100	Triassic	12	12	8.1	1.1	39.0	.6
Simsbury	91	Gneiss	10.5	12	8.5	1.9	2.1	.6
Avon	31	Triassic	12.2	13	19	1.8	3.5	.4
Avon	26.5	Gneiss	10.4	10	5.7	1.6	2.2	.4
Framingham	?	Triassic	12.8	24	26	9.3	6.0	.5
Framingham	132	Triassic	10.5	16	17	1.3	20.0	.8
Framingham	107	Triassic	12.2	13	31	5.3	3.7	.6
Bristol	46	Gneiss	11.6	27	17	7.8	6.7	1.4
Southington	130	Triassic	10	24	35	3.6	5.5	3.6
Plainville	67	Triassic	12.8	20	31	7.9	4.6	1.4
Bloomfield	185	Triassic	11	17	28	15	7.8	1.1
Glastonbury	76	Gneiss	12.8	15	6.3	1.3	3.6	1.7
Manchester	183	Triassic	12.8	14	27	10	2.3	.8
Portland	36	Gneiss	11.	12	33	5.3	9.1	1.9
MAINE:								
Presque Isle	94	Limestone	6	8.5	7.4	14	6.0	.5
Raymond	181	Granite	6.5	16	27	4.6	8.4	.6
Vassalboro	76	Schist	10.5	13	29	9.7	3.5	3.6
Charlestown	72	Schist	9.8	8.4	26	9.5	-	-
Newport	37	Limestone	9.8	8.5	73	7.0	2.3	.5
Monson	96	Slate	9.6	-	4.8	1.6	3.7	1.4
Bucks Harbor	52	Rhyolite	10.7	14	35	3.8	-	-
North Berwick	84	Schist	9.8	13	23	3.1	8.2	3.1
VERMONT:								
Bennington	42	Gneiss	9.7	14	8.2	5.3	6.9	.7
West Dover	26	Gneiss	9.9	16	13	9.6	4.4	.5
Newfane	35	Gneiss	8.9	11	21	5.1	3.9	.6
Chester	14	Serpentine	8.3	13	7	14.2	2.1	.4
Danby	21	Marble	9.4	9	29	13.	3.4	.8
Ludlow	11	Schist	9.1	14	11	6.2	4.5	1.2
Hartland	13	Schist	9.2	15	17	8.1	3.1	.6
Rutland	22	Schist	9.4	17	19	7.2	4.7	1
Pittsfield	15	Gneiss(?)	10.6	19	11	7.9	6.3	.8
Barre	22	Granite	7.8	21	9	4.7	7.2	3.1

TABLE 6

Water Temperatures from Selected Bedrock Wells of Massachusetts

LOCATION	DEPTH (m)	TEMPERATURE (°C)
Western Massachusetts:		
Dalton	194	7.8
Dalton	156	10
Dalton	58	10
Great Barrington	156	10.6
Lee	196	10
New Marlborough	9	7.2
Pittsfield	193	7.8
Stockbridge	75	9.4
Williamstown	152	12.8
Williamstown	113	8.9
Greenfield	47	9.4
Chicopee	138	8.9
Chicopee	155	13.3
Chicopee	246	13.9
Chicopee	215	9.4
Springfield	160	9.5
Springfield	105	10
Southeastern Massachusetts:		
Acushnet	30	14.4
Easton	64	12.8
New Bedford	7	10
New Bedford	15	15.6
New Bedford	12	10.1
New Bedford	4	12.2
North Attleboro	152	12.2
North Attleboro	105	7.2
Rehoboth	30	13.3

LOCATION	DEPTH (m)	TEMPERATURE (^{o}C)
Rehoboth	35	11.1
Rehoboth	34	12.2
Rehoboth	49	13.3
Rehoboth	93	10.6
Rehoboth	12	13.4
Seekonk	40	13.8
Swansea	60	13.9
Swansea	29	12.6
Somerset	457	17
Somerset	305	19
Taunton	154	13.7
Taunton	19	12.1
Taunton	154	12.2
Taunton	64	12.0
Northeastern Massachusetts:		
Boxford	56	11.0
Chelmsford	22	12.2
Dracut	53	12.3
Lowell	46	12.7
Newbury	59	9.3
Newbury	37	11.2

chusetts and Vermont. While no potential resource can be postulated for any of these regions as a result of this study a discussion of each is given herein to explain their selection.

The White Mountain Region

There has been much speculation over the past few years concerning the possibility of there being moderately high temperatures at depth within certain plutons that are a part of the White Mountain Magma Series. The relatively young plutons range in age from 110 to 182 m.y. (Tilton and Davis, 1951; Folard, 1970). Billings and his students (Billings, 1928; Billings and Williams, 1935; Henderson, 1949; Moke, 1946; Smith and others, 1940) delineated eight plutonic rocks of differing composition, which are considered to be consanguineous. Billings (1945) concluded that the intrusives were emplaced by cauldron subsidence and stoping. Geophysical studies on the Merrymaking stock in New Hampshire (Griscom and Bromery, 1968) support the suggestion of Chapman (1968) that the plutons represent cumulates and that they crystallized as floored intrusions with mafic rocks at depth.

The White Mountain Magma Series is composed of a group of plutonic and volcanic rocks that range in composition from gabbro to syenite. Of these, biotite granites near Conway and Waterville, New Hampshire, give the highest heat flow values (1.95 to 2.21 HFU - see Figure 7) of any so far determined in New England. The high heat flow is attributed by Birch et al. (1968) to the abnormally high concentrations of uranium, thorium and potassium contained in the granites. Osberg et al. (1978) have determined that the concentration of radioactive elements is fixed in allanite, huttonite, thorite and zircon, and dispersed in biotite, feldspar and quartz.

Birch et al. (1968), apparently using simple assumptions about the shape of the plutons and the distribution of the radioactive elements, calculated that the surface heat flow could be generated in plutons 6 to 10 km thick and would reach temperatures of 150° to 200°C at depths of between 4 and 5 km. Osberg et al. (1978) concluded from detailed gravity studies that the Conway granite is between 4 and 5.25 km thick. They further conclude from temperature modeling that the high heat flow which Birch et al. (1968) attributed to being derived primarily from concentrations of radioactive elements in the granites is open to question. Osberg contoured the heat flow values and suggests the existence of a north northeast trending ridge of high surface heat flow which he interprets to represent a "bump" in background heat flow. He suggests that the heat flow entering the crust at 10 km depth is larger (1.3 HFU) than elsewhere in New England (the 0.8 HFU value of Birch). Using the higher value for heat entering the upper crust they derived a temperature distribution model giving temperatures of 76° to 110°C at 5 km and 93° to 135°C at 5.25 km.

The Osberg study therefore suggests only minor temperature increases within and beneath the Conway and related granites. Field observations and literature search of the region yield no evidence of any springs or ground waters of even slightly elevated temperatures. Thus it appears unlikely that there is any potential for low temperature hydrothermal geothermal resources associated with the plutons of the White Mountain Magma Series.

The Narragansett Basin

Lyons and Chase (1976) report that the carboniferous rocks of the

Narragansett Basin (Figure 2, Plate I) are predominently conglomerate, arkose, graywacke, siltstone and shale with some coal. Only rough estimates of the total thickness of the sedimentary sequence are possible due to the scarcity of outcrop, rapid facies changes and structural complexities. The thickness probably lies between 2000 and 12000 feet. Mutch (1968) concluded that the region was an isolated inter-montane basin characterized by rapid deposition of various types of fluvatile sediments. He also believes the total thickness of the sequence to be close to 12000 feet. The more pelitic sediments have been metamorphosed to slate and phyllite and the metamorphic grade increases southward to staurolite grade in parts of southern Rhode Island. The sedimentary rocks are highly indurated and the permeability quite low. Frimpter and Maevsky (1979) report that in many core samples from test borings healed and unhealed fractures and slickenside surfaces were common, indicating that these rocks had undergone brittle deformation. Where the fractures are open ground water occurs under pressure, but yields are low. During 1977 the U.S.G.S. conducted pump tests on twelve observation wells and yields ranged from 0.36 to 30 gal/min with very slow recovery after pumping was stopped in all but one case. Four wells yielded water with temperatures above the normal 10 - 11°C ground water temperatures in the Basin. Two wells at Bristol, Rhode Island, both yielded water with the temperature at 15°C (59°F), and the water remained salty throughout the pump test. Two wells at Somerset, Massachusetts, one 1000 feet and the other 1500 feet deep, gave very low yields of water at 17°C (63°F) and 19°C (67°F) respectfully. The deeper well is located about 100 feet from the shore of Narragansett Bay and the specific conductance of the water rose from 510 to 880 during a three hour pump test indicating salt water inflow into the well. The elevated temperatures in the Somerset wells are probably caused by inflow of discharge from the nearby Brayton Point New England Power plant.

The Connecticut Valley

The present day Connecticut Valley is a topographic low developed by the erosion of Mesozoic age detrital sedimentary rocks. Geologically it is an asymmetrical structural trough or elongate basin that is fault-bounded on the eastern margin (Fig. 10). The development of the trough was controlled by physical differences in the underlying Paleozoic metamorphic rocks. The north-south trend follows zones of weakness defined by the low grade metamorphic rocks of the Connecticut Valley-Gaspe synclinorium, which separate the zones of mantled gneiss domes of the Berkshires to the west from the domes of the Bronson Hill Anticlinorium to the east. The geometry of the edges of the basin is influenced by local basement structures, especially the dipping flanks of the domes.

The Mesozoic age basin is divided into two sub-basins to the north and south of Amherst, Massachusetts. The northern portion, known as the Deerfield Basin, contains less than 1 km of detrital sediments and volcanics. The southern and more extensive part of the structural feature is known as the Hartford Basin, which extends south from Amherst to Long Island Sound. The thickness of Mesozoic age rocks exceeds 4 km under Springfield, Massachusetts. The two basins are separated as the result of a large intrusion of tonalite of Devonian age (the Belchertown Complex) that cuts across the rocks of the Connecticut Valley-Gaspe Synclinorium and into the west flank of the Bronson Hill Anticlinorium thus disrupting the north-south zones of structural weakness between the two

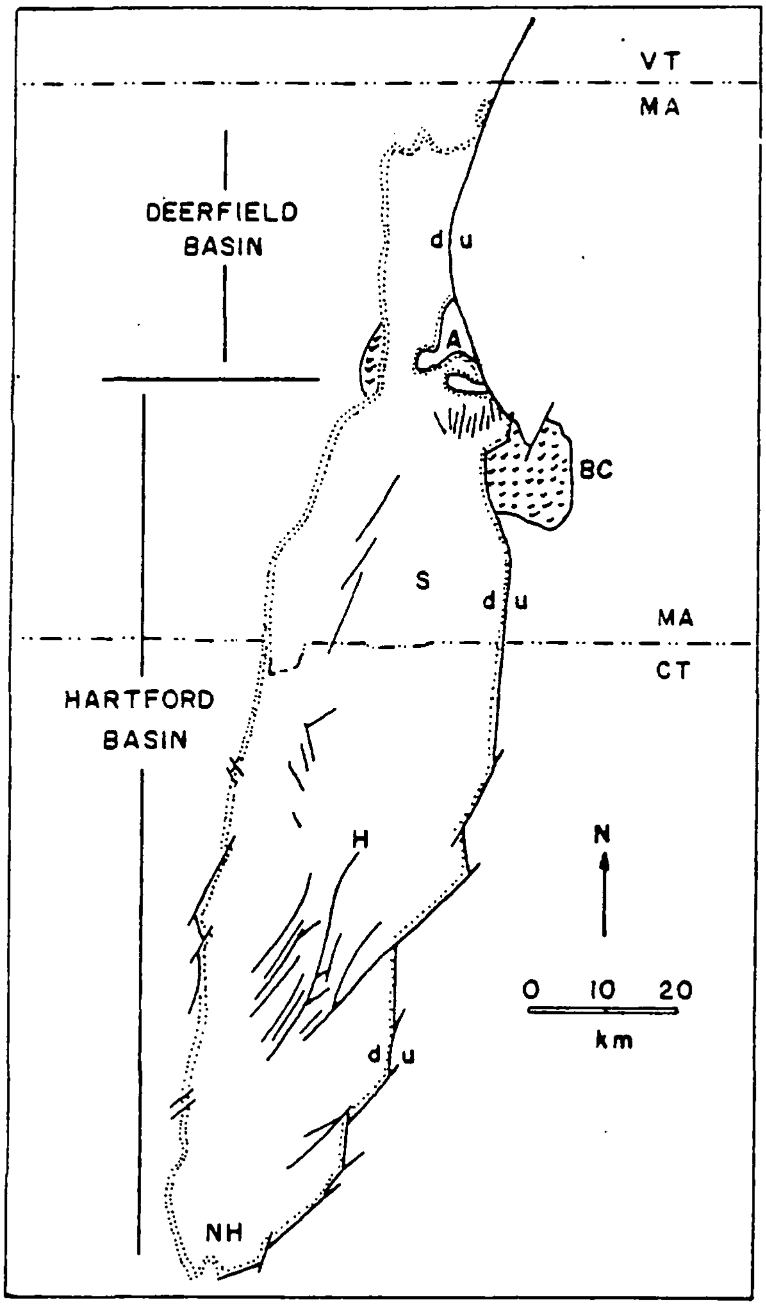

FIGURE 10: The Mesozoic Basin of the Connecticut River Valley is fault controlled on the eastern margin, and divided into two sub-basins separated by the Devonian age Belchertown intrusive complex (BC). Cities located are Amherst (A) and Springfield (S), Massachusetts and Hartford (H) and New Haven (NH), Connecticut. The western edge of the basin is an erosional contact denoted by the double-dotted line.

belts. Subsidence of the two basins was greatest on the eastern side along a westerly dipping listric fault system so the general dip of the Mesozoic rocks is to the east.

Wise (1979) and his students have been conducting detailed studies of the structures related to the basins and a number of patterns have emerged. They show that a trend of N30-40°E extensional structures dominates the region, especially within and east of the basins. These structures are represented by basalt dikes, veins, joint sets and normal faults. They conclude that much of the eastern border fault zone of the basins is composed of segments of faults of this type. In areas where the trend of the basin parallels the structural N30-40E trend the movement on the faults is dip slip, the trend is interpreted as being the regional extension direction during the early to middle stages of basin formation. Late stage movements on the faults controlling the basin appear to be of a strike-slip nature as indicated by slickensides on the fracture and fault planes.

Portions of the Belchertown intrusive complex contain an unusual amount of allanite, a member of the epidote group containing up to 3% thorium and rare earths. It was thought that the heat provided by radioactive element decay might be trapped by the overlying Triassic-Jurassic sedimentary rocks and provide a heat source for any deep circulating waters. Unfortunately the distribution of allanite is quite sporadic, and the principal concentration is found in that part of the complex which lies on the west side of the structural basin and is covered by only a thin veneer of sedimentary rocks. There are no known water wells in the area which penetrate into bedrock, since most of the valley region between the exposures of the complex to the east and west is mantled by a thick cover of glacial sediments.

The faults that bound the basin on the east side of the Connecticut River Valley are thoroughly cemented, show no evidence of any movement in historic time and are aseismic. Wells that do penetrate into the Triassic-Jurassic rocks show no evidence of elevated temperatures (see Table 5). One well, in Hadley, Massachusetts, was reported (Gruy Federal, personal communication) to be 250 feet deep and yielding water at 15.6°C (60°), but attempts to locate the well failed. This well, and all wells in Hadley, would overly the buried Belchertown complex but are completed in glacial sediment. All town wells are 70 feet deep or less and do not exceed 11°C (52°F).

The St. Johnsbury Thermal Anomaly

During the course of field investigation an unusual thermal anomaly was discovered in the town of St. Johnsbury in northeastern Vermont.

The town is underlain by Siluro-Devonian schists which are mantled with thick ice-contact glacial sediments forming broad terraces. The owner of the residence at 115 Main Street reported a small roughly circular area of about 15 feet diameter next to the house upon which snow would melt and only moss would grow, and further that this occurrence had been noted in diaries of former occupants in the 19th century.

During April and May, 1981, several visits to the site were made, and a series of auger holes drilled to lengths up to 8 feet. A probe recorded temperatures varying from 96°F to 105°F. The material in which the holes were drilled is a clean, dry sand. The following is an exerpt from a letter dated June 28, 1981 from the property owner.

> "In the afternoon I noticed again what I have noticed in the past, a slight gassy smell coming from the hole. Thinking it might be swamp gas in small quantity I eventually decided to try lighting it with a match, so at 5:15 p.m. I did so, and the hole burst into flame and kept on burning. Since there are now five holes in the hot area, I tried them all with matches and all burst into flame, though none as powerfully as the new hole. I should have done this last summer for I recall the gassy smell when I dug a hole with a shovel in the hot area."

The local utilities company has no record of any gas line in the area.

The source of the gas and the heat remains unexplained.

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GEOTHERMAL RESOURCE ASSESSMENT OF THE NEW ENGLAND STATES

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Work Performed Under Contract DE-FC07-80RA50272

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Geothermal Resource Assessment
of the New England States

Introduction

On July 1, 1980, a two year program to conduct an assessment of the geothermal resource potential of the New England region (Fig. 1) was initiated under contract DE-FC07-80RA50272 between the Department of Energy and Amherst College of Amherst, Massachusetts, at a funding level of $65,000. Subsequently a six month no-cost extension was granted to terminate the study at the end of 1982. Most of the field work was conducted during the summer months, with laboratory work and literature searches being pursued during the academic year.

Even though, for geologic reasons, there appeared to be only a small possibility that hydrothermal geothermal resources might occur in the region, the existence of warm springs in western Massachusetts, the abnormal radioactivity in certain plutonic rocks in the region, and the high population and industrial density justified a survey at a low level of funding.

Since modern day earth scientists, except for hydrologists and ground water geologists, pay little or no attention to springs and their characteristics, it was necessary to go back and pursue the early geological literature concerned with New England and this in itself raised a problem. Early investigators wrote in a most prosaic style and rarely had indices in which specific features were listed, so often it was necessary to read an entire work in search of clues to

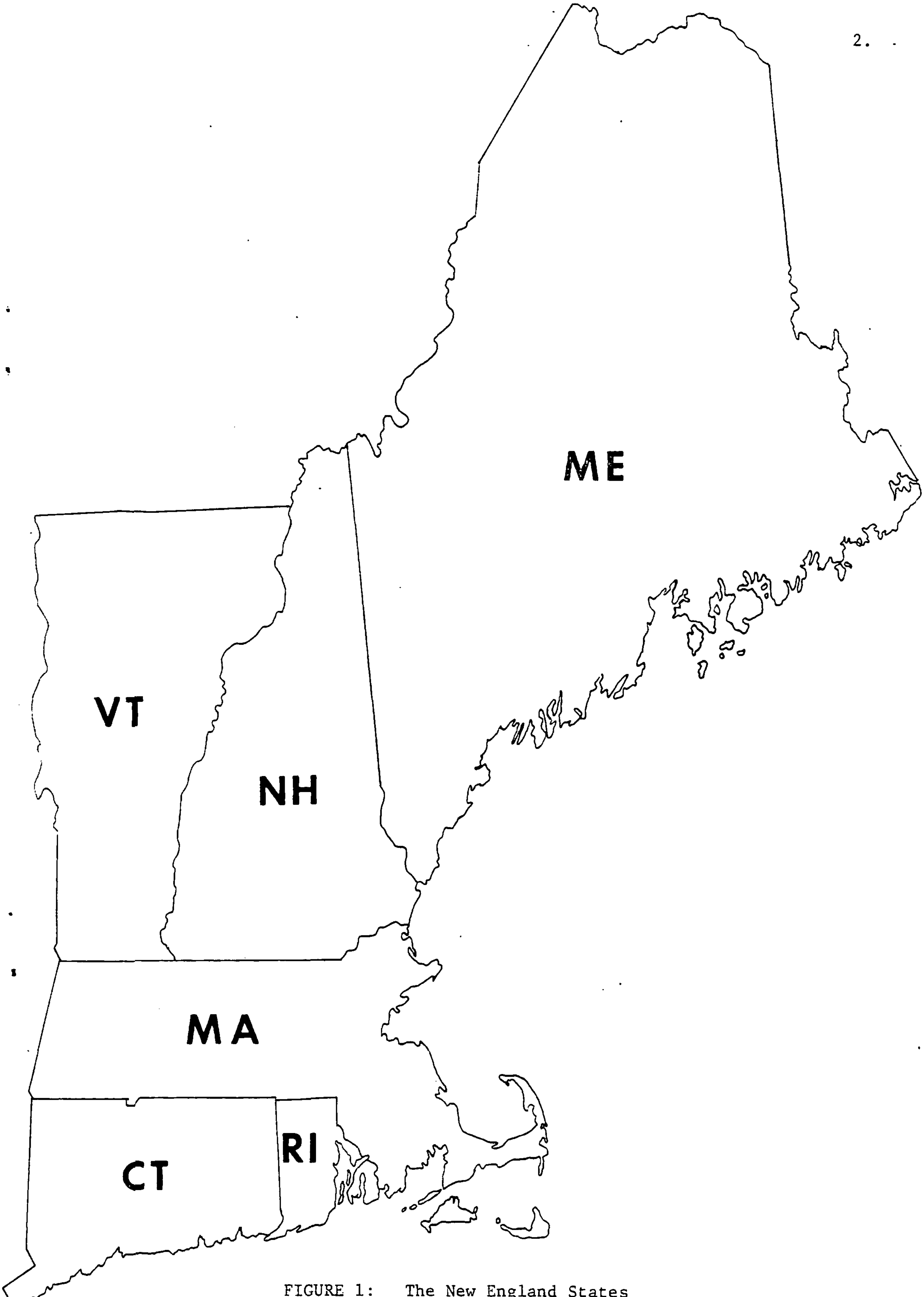

FIGURE 1: The New England States

springs of unusual character. Within these works the location of features are also vague and frequently given in terms of the current land owner and structures.

Early visits were made to the offices of the State Geologist, the State Energy Office, and the Water Resources Division Office of the U. S. Geological Survey, in search of information relating to springs and wells in the region. Compilation of geological and geophysical data have been made and compared in search of areas that could serve as targets for more detailed investigations.

Results of the Survey

With the exception of Sand Springs in Williamstown, Massachusetts, there are no identifiable hydrothermal geothermal resources in the New England region. The radioactive plutons of the White Mountains of New Hampshire do not, apparently, contain sufficient stored heat to make them a feasible target for an induced hydrothermal system such as exists at Fenton Hill near Los Alamos, New Mexico. The only potential source of low grade heat is the large volume of ground water contained within the unconsolidated sediments related to the Pleistocene glaciation of the region.

During the course of the survey an unusual and unexplained thermal anomaly was discovered in St. Johnsbury, Vermont, which is described towards the end of this report.

Summary of the Geologic History of New England

The oldest exposed rocks in New England (Plate I) are part of the Grenville Group of Precambrian age and crop out in the core of anticlinorial uplifts in western Vermont, Massachusetts and Connecticut. These rocks contain a long history, which includes repeated periods of sedimentation, deformation, metamorphism and intrusion. Rocks of Grenville age are believed to underlie virtually all of New England. The Grenville orogeny ended about 950 million years ago.

In Late Precambrian time rifting of the landmass containing the Grenville rocks occurred producing what some geologists term the "proto-Atlantic" ocean. Late Precambrian and Early Paleozoic sediments and volcanic material were deposited forming a continental shelf, slope and rise. Present day western New England contains rocks that were probably formed on the continental slope, with volcanic island arcs farther to the east. Continued erosion of the land mass to the west and north permitted the encroachment of the ocean westward creating large epeiric seas covering most of New England and the region to the west by Late Cambrian time and into Ordovician time.

The "proto-Atlantic" ocean began to close by Middle Orodvician time and deformation commenced with the advent of the Taconic orogeny. This deformation caused folding, thrusting, uplift and granodiorite intrusions of the Oliverian and Highlandcroft Magma Series (Plate II). The orogeny affected northern Maine and western New England and adjacent New York east of the Hudson River producing an elevated land mass. Erosion and sedimentation produced another sequence of continental margin sediments in Silurian and Devonian times but situated farther to the east in central Vermont, Massachusetts and Connecticut.

All of New England was again subjected to intense deformation (the Acadian orogeny) during Late Devonian time, producing intense metamorphism and intrusion of the New Hampshire Magma Series (Plate II). Erosion of the resulting mountain chain produced deltaic deposits that spread over much of the region during Pennsylvanian time. Large swampy areas developed on the deltaic deposits ultimately producing coal. These deposits are preserved today in Rhode Island and adjacent Massachusetts in the Narragansett Basin (Plate I).

In Late Pennsylvanian time or Early Permian time deformation again affected the region during the Appalachian orogeny, which in New England caused the folding, low grade metamorphism and granitic intrusion (Narragansett Pier granite) in Rhode Island and eastern Connecticut and Massachusetts.

Rifting began in Late Triassic time as a result of regional warping and associated faulting. Nonmarine, red fluvial and dark lacustrine sediments and basalts filled the rift valleys and basins into Jurassic time, creating the rock sequence now preserved in the Connecticut River Valley of Massachusetts and Connecticut and a much smaller basin in southwestern Connecticut.

In Late Jurassic time the present Atlantic Ocean began to open and the present continental shelf, slope and rise began to develop. While the oldest dated rocks in the shelf pile are of Jurassic age the oldest exposed rocks (at Martha's Vineyard) are of Cretaceous age. Associated with the opening of the Atlantic Ocean was the formation of a large group of calderas during Jurassic and Cretaceous time. The calderas and associated volcanic activity were centered in the middle of New Hampshire forming the alkalic igneous rocks of the White Mountain Magma Series (Plate II).

With the end of the volcanic activity the New England region has been subject to erosion with the exception of the advance of continental glaciers during Pleistocene time. The terminal morraines of the last advance are found in Massachusetts on Cape Cod, Martha's Vineyard and Nantucket Island. With the retreat of the ice sheet glacial till and lake deposits were spread unevenly over the entire region.

Tectonic Setting

The entire region of New England is essentially the northern extension of the Appalachian Mountains orogenic belt which in New England has been divided by Zen (1968) into several broad zones. (Fig. 2).Each of the zones forms a tectonically distinct geologic unit and usually has a distinct stratigraphy. It is perhaps easiest to discuss the zones from west to east across the structural grain of New England.

The westernmost zone associated with the Appalachian orogenic belt lies mostly outside of New England. This zone, termed the foreland, consists of rocks that are chiefly Cambrian to Middle Ordovician quartzites and carbonate rocks overlain by Middle Ordovician shale. The zone is to the immediate west of the orogenic belt and includes the rocks in the Hudson Valley and the Champlain lowland. The degree of deformation is very slight but increases to the east.

A north-south trending belt of metamorphosed Lower Paleozoic carbonate rocks forms the next zone, termed the Middlebury-St. Albans Synclinoria. The rocks correlate lithologically and stratigraphically

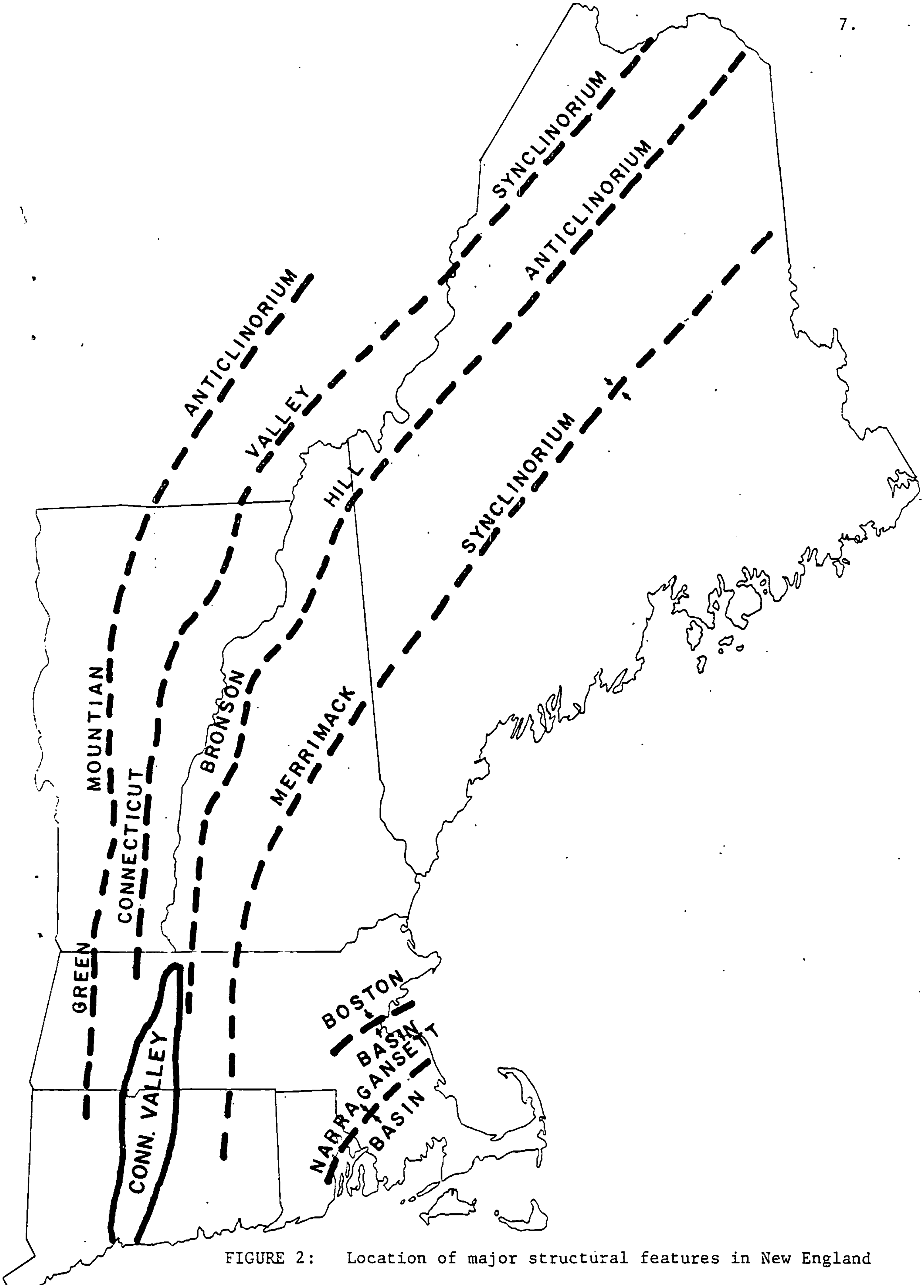

FIGURE 2: Location of major structural features in New England

with those of the foreland. They have, however, undergone two periods of deformation (the Taconic and Acadian orogenies). To the south the rocks are folded recumbently. The degree of folding diminishes northward and in western Massachusetts and Vermont the rocks are broken by thrust faults (Plate I). Within this belt of folded and faulted rocks is a zone of allochthones that slid into place from the east. They represent a facies that is intermediate between the platform sequence of the foreland and volcanic-bearing eugeosynclinal rocks. During Middle Ordovician time these masses slid into their present position as submarine "sheets", and are composed of rocks that range in age from Cambrian to Middle Ordovician.

The next zone eastward is dominated by large massifs of Precambrian rocks. In the New England region they are the Green Mountain massif (Vermont) the Berkshire massif (Massachusetts) and the Housatonic and New Milford massifs (Connecticut). They are the cores of large anticlinoria, the limits of which extend beyond the exposures of the Precambrian rocks.

The next zone to the east of the massifs consists of eugeosynclinal Paleozoic rocks that are intensely sheared, folded and metamorphosed to varying degrees. These comprise the western limb of the Connecticut Valley-Gaspe synclinorium. In New England this zone can be subdivided into two subzones. The western subzone consists of a homoclinal sequence dipping eastward off the massifs. The eastern subzone consists of domes superimposed upon isoclinal and possible recumbent folds. Ultramafic rocks are associated with both subzones.

The same eugeosynclinal sequence of rocks is exposed in the next zone, the Bronson Hill Anticlinorium, but here the structure consists of a series of knappes with a second line of gneiss domes superimposed on the nappes. The domes extend from northwestern New Hampshire to Long Island Sound.

The Merrimack Synclinorium comprises the next zone. It extends from northern Maine through central New Hampshire into eastern Massachusetts and Connecticut. Stratigraphically, rocks of this zone correspond to those in the Connecticut Valley-Gaspe Synclinorium from which they are separated by the gneiss domes of the Bronson Hill Anticlinorium.

The coastal belt is composed of a heterogeneity of eugeosynclinal rocks containing a large volume of volcanic and nonmarine rocks. These are probably of Ordovician, Silurian and Early Devonian age. There are also rocks of possible Precambrian age in southwestern New England.

Superimposed on these zones of pre-Arcadian rocks are two sequences of younger non-marine rocks, namely the Pennsylvanian age Narragansett and Boston basins and the Triassic-Jurassic age basin of the Connecticut River Valley. Both of these sequences probably covered most of New England at the time of deposition but have subsequently been removed by erosion.

The zones outlined above, with the exception of the Triassic-Jurassic basin, have been variously affected by one or more orogenies since the beginning of Paleozoic time, and evidence of additional orogenic events can be found in the Precambrian rocks. The Paleozoic orogenic events provide a useful reference for gross division of the stratigraphic column as used on the geologic map (Plate I).

The Taconic orogeny affected rocks of Cambrian and Ordovician age, so rocks of those ages are grouped as one unit on the geologic map.

This orogeny was apparently long lived, beginning in isolated localities in the Middle Ordovician and may include some events that occurred as late as Late Silurian time. The time between the Taconic and Acadian orogenies is represented by the deposition of Silurian to Middle Devonian rocks in New England. The Acadian orogeny had far greater affect on New England than either the Taconic or the later Appalachian orogenies, producing a higher grade of metamorphism and a large volume of plutonic rocks, which persisted from preorogenic to post-orogenic time. It was also responsible for the formation of the synclinoria and anticlinoria and the formation of most of the nappes. The Appalachian orogeny affected the late Paleozoic rocks of eastern Massachusetts and Rhode Island.

The Triassic-Jurassic detrital and volcanic rocks are confined to the partly fault-bounded basin in central Massachusetts and Connecticut, are unmetamorphosed and therefore truly post orogenic. Thus in New England the late tectonic events appear to be restricted to high-angle faulting accompanied by volcanism and the emplacement of the White Mountain Magma Series.

Bouger Gravity Anomalies in New England

The first gravity map of the region was prepared by Longwell (1943) and covered a portion of southern New England. It was followed by a map and report by Woolard (1948) covering most of New England. These, and subsequent more detailed investigations (Bean, 1953; Joyner, 1963; Bromery, 1967; Diment, 1968; Kane and Bromery, 1968; Kane, 1970) have been combined by Kane et al. (1972) to produce a Bouguer gravity map of the region. The gravity map accompanying this report (Plate III) is a modification of the map of Kane et al. (1972).

Negative gravity values are dominant throughout New England and exceed -70 milligals in northwestern Massachusetts, southeastern Vermont and central New Hampshire. Positive gravity values exceeding +40 milligals are located in southwestern Connecticut and in the Cape Ann region north of Boston (Plate III).

Gravity trends are mostly north-south in western and southern New England and shift to a northeasterly trend in the rest of the region becoming most pronounced in Maine. The diversity in trend correlates in a general way with lithology and structure (Plate I).

Regional gravity anomalies are considered to be the result of variation in crustal thickness (Kane et al., 1972). Local anomalies appear as a sharp steepening of gradients and local closure of isogals. In New England the best defined cause of local, steep anomalies are masses of plutonic rock, the most common being felsic plutons associated with gravity lows. The pile of sedimentary rock in the Narragansett and Boston Basins does not produce a gravity low, probably as a result of the low grade metamorphism that accompanied the Appalachian orogeny. Likewise, the thick pile of post-tectonic sediments in the Connecticut River Valley does not give any indication of there being an associated gravity low probably due to their thorough cementation (in part of section by iron carbonate and iron oxide) and the presence of lava flows.

The regional gravity field correlates well with major geologic features, with gravity highs overlying broad areas of uplift and the lows over broad areas of subsidence and deposition (Longwell, 1943; Woolard, 1943). Two of the regional lows occur over large felsic plutons, one being the White Mountains of central New Hampshire within the Merrimack Synclinorium and the other in extreme northeastern Vermont within the Connecticut Valley-Gaspe Synclinorium.

The correspondence between tectonic features and major gravity features is apparent on a large scale, but does not hold in detail as noted by Diment (1968). Note, for example, the offset of gravity and tectonic highs in extreme western Massachusetts. It would seem, therefore, that the regional anomalies are caused by major crustal or crust-mantle structures of considerable vertical extent that are sometimes masked by geologic features within the upper crust such as the multiple thrusting of thin crustal sheets in western New England.

The predominate regional features of the western part of New England are the positive linear gravity high and the adjacent gravity low to the west (Plate III). Diment (1968) concluded that the principal cause of the high is the relative uplift of dense lower crust material while the low results from the depression of less dense crustal material into the more dense mantle. The gravity field in extreme western New England shows a range in gravity values over the relatively short distance of 125 km from + 40 mgals in southwestern Connecticut to - 65 mgals along the New York-Massachusetts border. This is in sharp contrast to the range/distance relationship in the rest of New England.

Another regional gravity low is more subdued and narrower than that in extreme western New England and occurs along the southern Vermont-New Hampshire border and extends into central Massachusetts. This low corresponds well with the Bronson Hill Anticlinorium which is composed of mantled gneiss domes and nappes. While local gravity lows appear over the domes, the more extensive feature is probably the result of the presence of a broad band of low density felsic material at depth below the anticlinorium.

The regional trend of the gravity field in the eastern two thirds of New England is northeast and parallel to the principal trend of the Appalachians. The regional field diminishes northwestward from the Gulf of Maine to the Canadian border. In Maine the local variations in the gravity field are associated with differences in lithologies, except in southeastern Maine over rocks that lie within the sillimanite isograd. (Plate III). Local gravity lows with sharp closure occur over Devonian age plutons. The large, elongate gravity low in northern Maine along the International Boundary is associated with the lower Paleozoic rocks of the Connecticut Valley-Gaspe Synclinorium . In southwestern Maine, most of New Hampshire, eastern Massachusetts, eastern Connecticut and western Rhode Island there is little correspondence between gravity lows and the Devonian age plutons. This large area of New England contains rocks that have been metamorphosed to sillimanite grade. Thompson and Norton (1968) have concluded that rocks within the sillimanite isograd were buried to at least 20 km based on metamorphic mineral equilibria. Exposure of these rocks at the surface may well indicate that the deep erosion accompanying uplift has removed most of the Devonian age felsic plutons. The deep gravity lows over the White Mountains are caused by the plutons of Jurassic and younger age which postdate the metamorphic event.

There is also a notable correspondence between gravity lows and topographic highs over much of New England, suggesting that the highlands are isostatically balanced by low density masses at depth. A major exception is the gravity low associated with the Green Mountain-

Sutton Mountain anticlinorium and the gravity low just westward over the Lake Champlain lowland. Since both of these regions are underlain by masses of complexly overthrust sheets of rock it is presumed that the crust in this region possesses enough lateral strength so that the load imposed by the overthrust sheets (the anticlinorium) is supported by the underthrust sheet (the lowland).

Seismicity

The level of seismicity, and the accordingly varied earthquake intensity, varies greatly from place to place in the northeastern United States. Although the region does not lie in a belt of major seismic activity, many earthquakes have been recorded since arrival of the first European settlers, and one area, Moodus, Connecticut, was sacred to the Indians because of the numerous tremors occurring there. The largest recorded seismic event (estimated intensity of VIII) occurred off Cape Ann, Massachusetts in 1755. Currently about 30 to 40 earthquakes are recorded yearly in the New England region.

Within New England there are certain areas (Figure 3) of higher seismiscity which appear to have remained stable over the last 300 years according to available historical records (Hadley and Evine, 1974). Recent, more accurately measured earthquake epicenters (Figure 4) for the period from October 1975 to June 1978 (Chiburis et al., 1978) fall within those areas of higher seismic activity in central New Hampshire and southern New England. However, the rate of activity within the areas of higher historical seismicity has been varied. For example, the area around Boston and Cape Ann was active in the first half of the Eight-eenth Century but has been quiet in more recent times. (Compare Figures 3 and 4).

Sbar and Sykes (1973) discussed the concentration of epicenters between Boston and Ottawa, Canada and suggest that the epicenters form a seismic zone. While it appears that a clustering of epicenters forms a zone from the north end of Lake Champlain to Ottawa, extension to the southeast is far from certain. The area of north-trending clustering of epicenters in eastern New Hampshire and the low seismicity belt of Vermont and Western Massachusetts conform to the regional structural trend and cut across the proposed Boston-Ottawa seismic belt of Sbar and Sykes.

A number of different causes have been called upon to explain the seismic activity in New England. Isostatic adjustment following deglaciation, stress accumulations at the borders of bodies of mafic rock due to density contrasts, reservoir filling and faulting have all been suggested as the possible causes for the seismic activity. None of these suggested causes can fully explain the distribution pattern of New England earthquakes, however.

Isostatic rebound due to ice unloading is certainly possible for the cause of some of the events, but in two areas of high seismic activity along the Maine coast the crust is sinking. The largest concentration of mafic rocks in New England lies within the belt of low seismicity of Vermont. Earthquakes do appear to be spatially related to the Mesozoic calderas in New Hampshire. The filling of the large Quabbin Reservoir in central Massachusetts has not generated any noticeable change in the local seismic activity. Movement along fault segments is considered the most likely cause of the earthquakes. Fault plane solu-

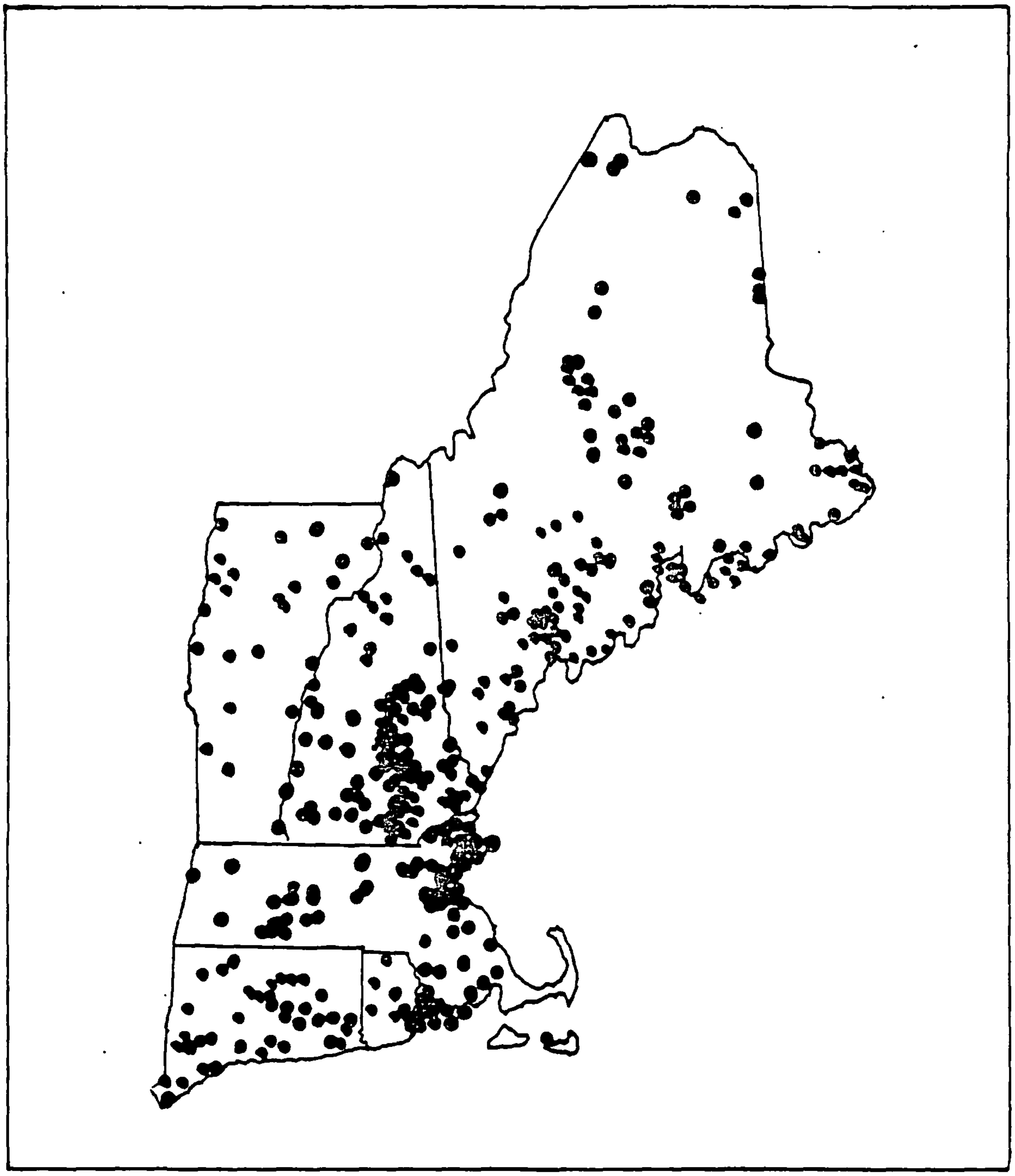

FIGURE 3: Recorded seismic events in New England from 1534 to 1977 (From Barosh et al., 1979)

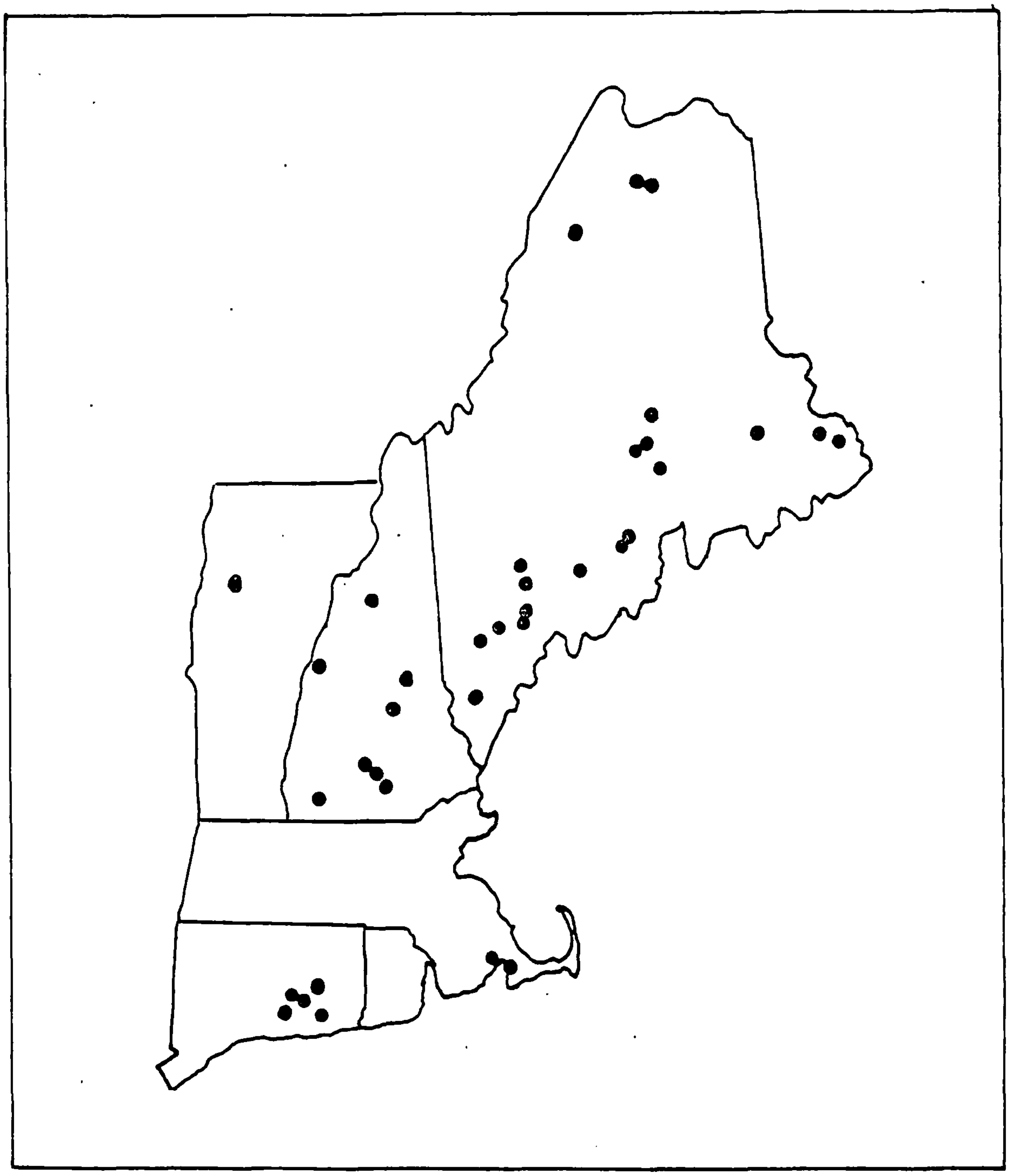

FIGURE 4: Recorded seismic events in New England for the period October 1975 to June 1978. (From Chiburis et al., 1978)

tions made from seismograph records from New England also suggest indirectly that the earthquakes originate on faults. However, there is no record of any surface fault movement accompanying a New England earthquake and nowhere in the literature is there any mention of an active fault. Since detailed mapping in New England has only begun in the 1930's there is not enough information available to reveal a basic tectonic pattern. Eastern Massachusetts and Connecticut are now known to be highly faulted and the rest of southern New England is probably equally as faulted (Figure 5). As for northern New England there has been little detailed mapping, but where it has been completed suggests that faults are abundant. The present evidence suggests major northeast zones of faulting across New England, with north and northwest trends being less abundant.

Major problems arise when attempting to date faults or periods of faulting. Many of the mapped faults in New England are of a compressional nature and are of Paleozoic age (225 5o 600 .m.y.), which may have been selectively reactivated. Also, there are very few areas of Mesozoic (65 to 225 m.y.) rock and virtually no Tertiary (1.8 to 65 m.y.) rocks, and where they do exist they are mantled by glacial till. The age of faults that cut the Mesozoic rocks is unknown but must predate the Cretaceous peneplanation that affected all of New England.

It would appear that areas of high seismicity are associated with zones of known or probable faults, but not with the zones of Paleozoic age compressional faults found in western New England. Zones of Mesozoic age high angle extensional faults are in some causes areas of high seismicity: the Champlain lowland, the southern Connecticut River Valley, the Narragansett Bay area, and the White Mountains of New Hampshire.

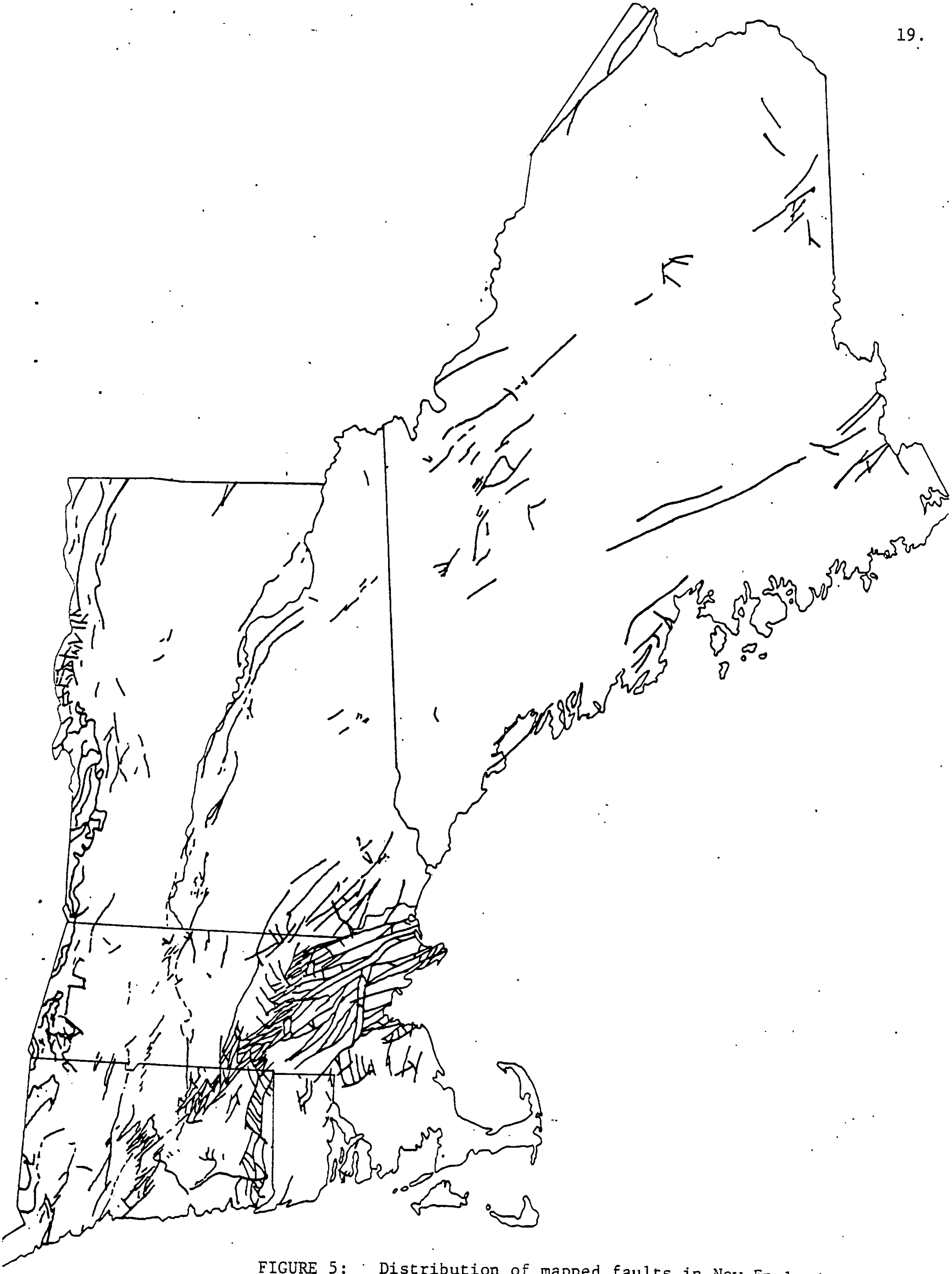

FIGURE 5: Distribution of mapped faults in New England

Except for seismic events in and near the White Mountains, the active areas of the New England region that have been instrumentally recorded occur in lowlands, bays, and major river valleys. These geomorphic features are directly related to the geology of the region. The lowlands are underlain by weak or soft rocks or have formed by extensional faulting and subsidence. Historic earthquake activity in New England therefore may be related to extensional faulting and may indicate minor rifting (Barosh, 1979).

Lineament Patterns in New England

The Mesozoic basins of Connecticut were studied by Hobbs and the first lineament maps were prepared in 1901, 1904, and 1911. He was among the first to recognize the existence of regional topographic lineaments. This pioneering work drew much attention and disbelief. More recently D. U. Wise and his students at the University of Massachusetts, Amherst, have been conducting fault, fracture and lineament studies in New England, particularly in western Massachusetts and Connecticut.

Wise (1976) noted that throughout New England the most pronounced linears are oriented N20E, N25W and N70E, of which the N25W set is the most pervasive. These linears cross all major tectonic boundaries in New England and hence must post-date the Paleozoic metamorphic events and the Late Paleozoic to Middle Mesozoic basin and caldera formation.

Comparison of the linear trends (Figure 6) and the faults of the region (Figure 5) clearly shows that the topographic linears are not great fault lines. However, Truesdell and Wise (1975) show that the linear trends correlate with small (up to a few meters displacement) fault orientations in a restricted area of western Massachusetts. Whether this correlation holds throughout all of New England is unknown at this time.

Wise (1976) interprets the linears in New England as beginning as incipient faults of a few tens to a few hundreds of kilometers of length following regional stress trajectories. They may become small faults, fault zones or zones of more intense development of joints. In the case of joint concentrations the joints need not parallel the zone itself, but merely be more intensely concentrated within the zone. Once formed these linears will maintain their existence, even penetrating sedimentary cover, by concentrating along them tidal strains, younger tectonic strains or the effects of propogation of seismic waves. At the surface the zone, be it fractured or faulted, provides easy access for ground water and deeper weathering to allow etching and preservation as elements of the topography.

Heat Flow

To date there have been seventeen heat flow measurements completed

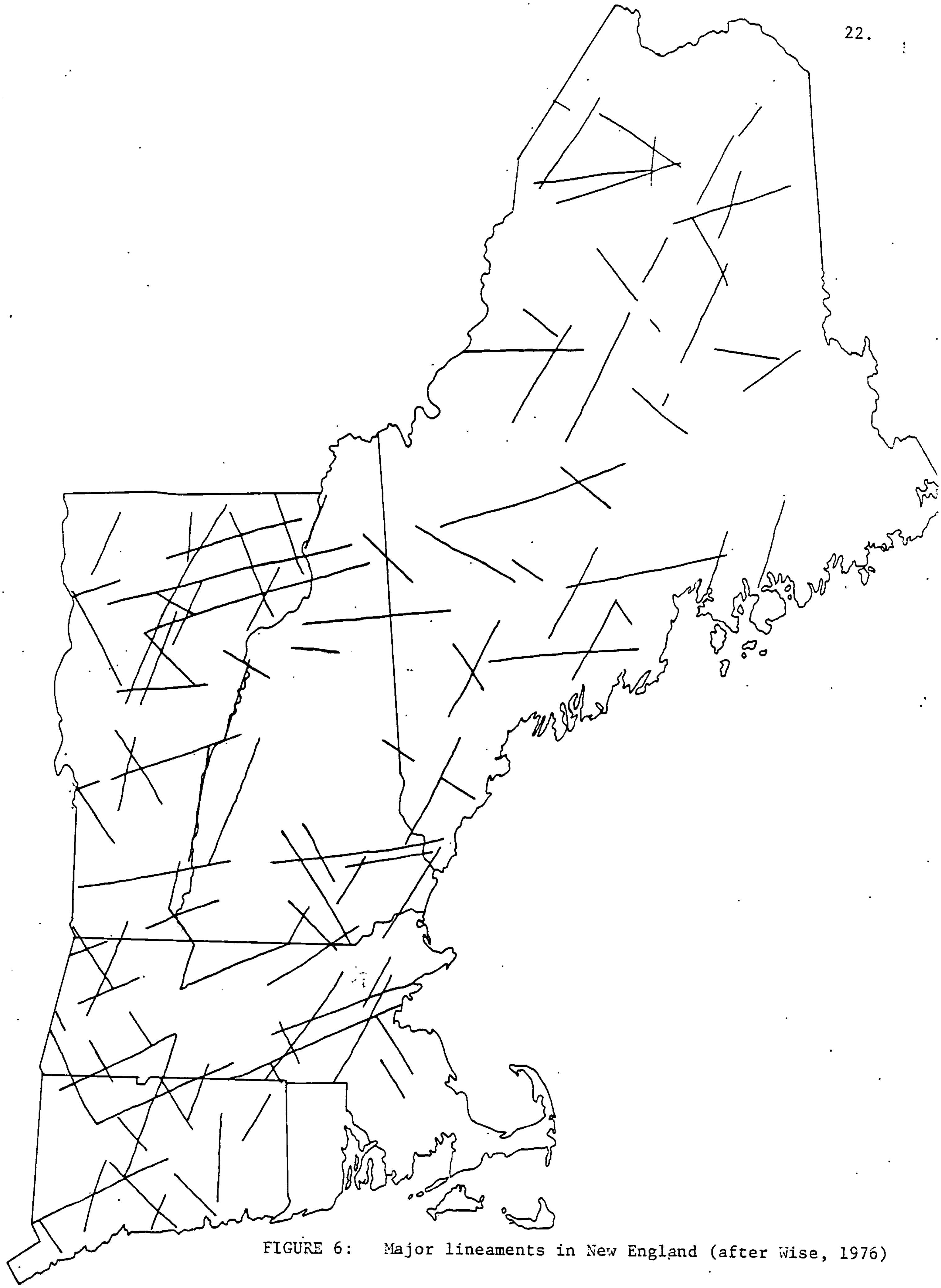

FIGURE 6: Major lineaments in New England (after Wise, 1976)

within the New England States. A detailed discussion of the thermal history is contained in Birch et al. (1968). The locations of the heat flow sites are given in Table 1 and Figure 7. The geologic distribution of the sites shows that the majority have been confined to Paleozoic-Mesozoic plutonic rocks in New Hampshire (eight), Massachusetts (two) and Maine (two). The three sites in Vermont are located in the Precambrian core of the Green Mountain anticlinorium. Of the twelve sites positioned in plutonic rocks three are located in the highly radioactive Conway granite (185 m.y.) of the White Mountain Magma Series, and the remainder in New England rocks of the New Hampshire Magma Series (360 m.y.). The highest heat flow values (Q) in New England are found in the Conway granite and the lowest in the Precambrian rocks of Vermont.

Since the bulk of the heat flow determinations in New England have been made in New Hampshire from rock of Devonian age or younger, Birch et al. (1968) have postulated a thermal history for New England (i.e., New Hampshire) beginning with Lower Devonian time. At that time there already existed in New Hampshire about 10 km of Ordovician and Silurian sediments deposited over a span of 100 m.y. Starting in Devonian time the rate of deposition increased and 15 km or more of deposits accumulated over a span of 50 m.y., which was followed by deformation, uplift and intrusion of the New Hampshire Magma Series comprising the Acadian orogeny. Erosion and uplift continued throughout the rest of Paleozoic time. During Triassic time another period of volcanism began in New England accompanied by the emplacement of the White Mountain Magma Series of which the Conway Granite represents the final phase. Since that time New England has been subject of slow uplift and erosion with a minor interruption during the Pleistocene glacial advance.

TABLE 1

HEAT FLOW IN NEW ENGLAND

LOCATION	Heat Flow Microcals/cm^2 sec. Topographic Corrected	 Geologic Corrected
Blue Hill, ME	1.44	1.30
Casco, ME	1.80	1.63
Brewster, MA	1.16	1.29
Cambridge, MA	1.20	1.20
Chelmsford, MA	1.63	1.48
Millers Falls, MA	1.67	1.51
Bradford, NH	1.59	1.44
Concord, NH	1.73	1.57
Durham, NH	1.08	0.98
Fitzwilliam, NH	1.63	1.48
Kancamagus, NH	2.27	2.13
North Conway, NH	1.89	1.95
North Haverhill, NH	1.34	1.21
Waterville, NH	2.15	2.21

From Birch et al., 1968

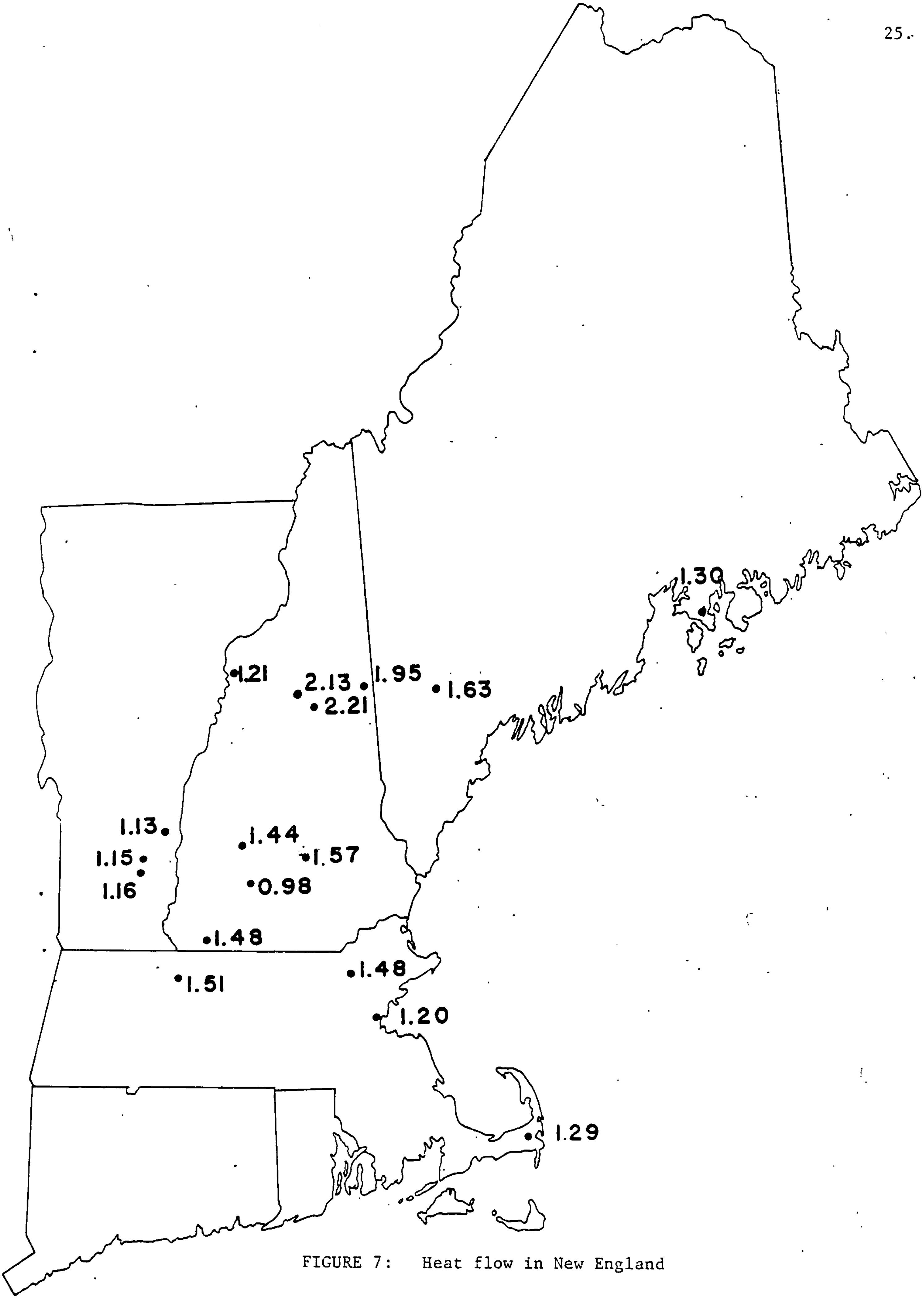

FIGURE 7: Heat flow in New England

The net effects of varying rates of sedimentation, intensity of metamorphism and the depths of emplacement of plutonic rocks (15 km for the New Hampshire Series versus 6 km for the Conway Granite) and erosion rates have altered the normal heat flow regime such that corrections have to be applied. However the magnitude of the "geological" corrections is not great (Table 1).

The correction for erosion effects are best applied to sites in New Hampshire, namely Bradford, Concord, Fitzwilliam and also Chelmsford, Massachusetts and Casco, Maine, all of which lie within the belt of deep Paleozoic sedimentation. Less certain is the application of erosion-rate correction at Blue Hill, Maine, North Haverhill and Durham, New Hampshire, and Millers Falls, Massachusetts. However, for the above Birch et al. (1968) have calculated a mean geothermal gradient of 18.3°C/km from averaged measured gradients with a mean value of 20.2°C/km thus providing a reduction of 9.4% in the topographically corrected values for heat flow. For the heat flow values calculated for the sites in the White Mountain Magma Series (North Conway, Kancamagus and Waterville, New Hampshire) a correction factor of 1.6°/km was subtracted from the gradients. The same correction factor has been applied to the gradients measured at the three sites in Precambrian rocks in Vermont. In the case of the site at Brewster, Massachusetts on Cape Cod, a 10% upward correction was applied to take into consideration the deposition of about 100 meters of sand following the retreat of the Pleistocene glaciers.

M. P. Billings (1964) prepared a map (unpublished) in which he contoured "equivalent uranium" (eU) for Maine, New Hampshire and Vermont. The quantity eU was used to show the gamma activity from uranium, thorium and potassium in terms of the amount of uranium and daughter products in equilibrium required to produce the same effect. Although the formula used by Billings ($eU_{gamma} = U + 0.48Th + 3K$; U and Th in ppm, K in percent) is different from that to calculate equivalent uranium for heat generation ($eU_{thermal} = U + 0.27Th + 0.37K$), eU_{gamma} is roughly proportional to A, the rate of heat generation per cm^3. Therefore a correlation between heat flow (Q) and A also provides a correlation between heat flow and eU. Birch et al. (1968) noted a strong correlation between heat flow values and eU contours of Billings and concluded that contours of bedrock eU can be converted to heat flow contours with errors on the order of 0.2 $microcal/cm^2$ sec for the region.

Heat flow values for the Precambrian anorthosite in the Adirondack Mountains of New York average 0.8 $microcal/cm^2$ sec and this value is attributed to be the contribution of the lower crust and mantle to the flux. Subtracting that amount from the calculated heat flow in the Conway Granite leaves 1.2 $microcal/cm^2$ sec to be supplied by radioactive decay in the granite. Assuming even distribution of radioactive elements in the granite, Billings et al. (1968) calculate upper limit of the thickness of the Conway Granite to be 6 km, which is reasonable agreement with an estimate of 4.5 km thickness required to explain the gravity low (Joyner, 1963).

New England Ground Water Resources

Most of the ground water resources in New England lie in the region defined by the U. S. Water Resources council as the Glaciated Appalachians region, the exception being Nantucket, Martha's Vineyard and Cape Cod which lie in the Coastal Plain ground water region. In the region average annual temperature ranges from 3.3°C (38°F) in northern Maine to 10°C (50°F) in Connecticut, Rhode Island and southeastern Massachusetts. The annual average precipitation ranges from 1000 mm (40 in.) in the north to 1140 mm (45 in.) in the south. By 1975 ground water constituted twenty-three percent of the total fresh water withdrawals in the nation. In New England ground water contributed twelve percent of the total fresh water withdrawals.

Most of the New England region is underlain by impermeable crystalline rocks from which small amounts of ground water are retrieved for domestic and livestock supplies from fracture zones. Sedimentary rocks in the region consist of carbonate and clastic sequences. The carbonate rocks, consisting of limestone, dolomite and calcareous shales, occur in the Hoosatonic River Valley in western Massachusetts and Connecticut and in the Aroostock Valley in northern Maine. Wells drilled in carbonate rocks can produce substantial ground water supplies if large solution openings are penetrated in the zone of saturation. The non-carbonate sedimentary rocks are mostly confined to the Connecticut River Valley lowland and consist of shale, sandstone, arkose, conglomerate and interbedded basalts. The sedimentary rocks yield small to moderate supplies, some wells providing as much as 19L/s (300 gal/min).

In parts of New England low grade metamorphosed sedimentary rocks yield small to moderate supplies of water. Rocks of this type, consisting of metaconglomerate, argillite, phyllite, slate and marble, occur widely in Maine, in western Massachusetts and western Connecticut, northwest of Boston, and in the Boston and Narragansett Basins of eastern and southeastern Massachusetts and southeastern Rhode Island. In a few places supplies up to 32L/s (500 gal/min) are obtained from strongly fractured zones.

The most productive sources of ground water in New England are unconsolidated sediments, which consist of glacial and glaciofluvial deposits and the reworked glacial deposits in present day river and stream valleys, termed watercourse aquifers. Thomas (1952) defines watercourses as hydrologic units that include both surface water of a river channel and the ground water in the alluvium that forms the flood plain. The glacial deposits in New England consist mostly of stratified drift (sand and gravel) with moderate to high permeability. The watercourse aquifers provide the highest yields of ground water with some individual wells yielding up to 125L/s (2000 gal/min) due to hydraulic continuity between the river and surrounding porous and permeable glacial outwash that underlies the flood plain. With the retreat of the glacial ice front northward at the close of Pleistocene time large volumes of melt water produced deep river channels, which were later filled with alluvium. With the reduction in discharge and subsequent land uplift that accompanied the glacial retreat, many of these river courses have been greatly reduced in size and some completely abandoned, and remain today as deep valleys filled with alluvium. They have an extent, thickness and permeability far greater than present streams could possibly produce, and some no longer form any part of the present drainage system. However, the opportunity for recharge may, in many cases, be limited to direct infiltration from precipitation and the perennial yield is likely to be less than that of the watercourse aquifers.

The contribution of ground water to the total discharge of a river is the base flow. The mean stream flow (Sinnott, 1982) for the New England Region has been determined to be about 258 x $10^2 m^3/d$

(68×10^9 gal/d). Using a conservative estimate of a base flow of forty percent of the mean stream flow of the entire region the average total yield of groundwater to discharge is about $102 \times 10^2 m^3 d/$ (27×10^9 gal/d). The large volume of lateral discharge of ground water in glacial till and alluvium that mantles all of New England therefore will in most cases dilute and mask any heated water that might be discharged at the bedrock surface.

Use of Ground water as an Energy Source

Technology Property Associates (TPA) of Burlington, Massachusetts, has constructed an office building that uses ground water for both heating and cooling purposes as a backup for the primary solar energy system. The system is maintained and operated by Aerospace Systems, Incorporated which states that although the system was designed as a backup, the water-to-water heat pump is able to extract 3 1/2 times more useable energy from water than an electrical resistance heating element could produce, and could be the primary energy source in a properly designed building in New England.

The extraction of energy from water courses has been proposed for the City of Stamford, Connecticut, through which the Rippowan River flows. The proposer, Wormser Scientific Corporation of Stamford, notes that the ground water conditions in Stamford are well known as the result of over 500 borings taken in conjunction with planning and construction of a 130 acre urban renewal project and the earlier construction of Interstate Highway I-95.

Two main shallow aquifers traverse Stamford in a N-S direction and one of these is rated as being capable of supplying 2.8 million gallons per day on average for consumptive use, i.e, without any return of the water to the aquifer. The water temperature varies between 10°C (50°F) and 11°C (52°F) annually. The proposer (personal communication, Wormser Scientific Corporation) plans to extract water from the aquifer to cool structures and return this water, now warmer by 5° to 8°C by their calculations, to the aquifer at a different location. It is this system that currently is in use in the TPA structure. They state that the direct distribution aquifer cooling system uses about 10% of the electrical energy requirements needed to operate a conventional air conditioning cooling system. Heat pumps in the heating mode extract heat from ground water at 10°C and amplify it using a compression refrigeration cycle to around 37°C (100°F) for heating purposes. The reinjected water will be cooled to around 5°C, but the amount of water removed and reinjected into the aquifer will be a small fraction of the total volume available.

The very large volume of ground water available in New England makes this resource a potential source of energy using water interface heat pumps.

Thermal Springs in New England

Seepage springs are abundant in New England, especially at the contact of glacial till and bedrock. There are some springs, however, that are fracture controlled and apparently circulate meteoric water to sufficient depth to become heated by the normal geothermal gradient.

A search of the literature, particularly that of the nineteenth century, was conducted to establish the existence of any possibly warm springs. In a report on the geology of Vermont, Adams (1848) makes note of Morgan Spring in the center of Bennington as possibly being a warm spring. Stearns et al. (1937) report that the spring was listed again in 1934 as a thermal spring with a temperature of 11.7°C (53°F) which is 4°C above the mean annual temperature. The spring is not listed by Waring (1965) nor Berry et al. (1980) and a visit to the area failed to locate the spring.

Daubney (1839) reported another slightly warm spring at Cannan, Vermont, but no subsequent listing could be found, nor could the spring be located.

Hitchcock (1861, p. 174) in a report on the geology of Vermont noted a number of springs producing calcareous deposits. When visited these proved to be normal ground water springs in a carbonate terraine.

Lebanon Springs - Sand Springs Area of New York and Massachusetts

Both Lebanon Spring in eastern New York and Sand Spring in Williamstown, Massachusetts have somewhat elevated temperatures that have been utilized for a number of purposes over the past decades. Lebanon Spring is located in the northwest corner of the Pittsfield west 7 1/2 quadrangle and lies about 17 miles south-southeast of Sand Springs.

At Lebanon Spring a 400 room hotel named Columbia Hall was built in 1794. The structure was removed in 1928 ironically because of the high cost of conventional heating. The Rutland Railroad laid a mile long pipe line from the spring in 1906 for recharging locomotive boilers. After abandonment of the railroad about thirty local families tied into the line and use the warm waters for domestic purposes. At the present time there is no use of the spring waters related to elevated temperature.

Sand Spring has been in use since pre-Colonial times. Carlin (1972) states that the spring was used by area Indian tribes as a landmark and campground for hunting and war parties, lying near the intersection of a north-south trail and the Mohawk Trail. A health spa, Graylock Hall, containing 26 large baths and 6 sunken bathing pools was built in the 1880's. A bottling works was added in 1893 and ceased production in 1972.

The most recent geological study of the Lebanon and Sand Springs by Dunn Geoscience Corporation for New York State Energy Research and Development Authority (1981) states that the thermal waters issue from Cambro-Ordovician rocks involved in the thrust belt of western New England and eastern New York. They interpret the elevated water temperatures to be the result of deep ground water circulation along permeable zones created along thrust fault planes. In the case of Lebanon Springs, Cambrian age phyllites have been thrust westward over Ordovician dolomite, and the dolomite has been as a result tensionally fractured to provide permeability (Fig. 8). Since the geothermal gradients in the area do not appear to be high it is estimated that water circulation to about 1 km depth could account for the 22°C (72°F) measured at Lebanon Spring.

The thermal springs at Williamstown, Massachusetts, may occur in a slightly different geologic setting. The springs occur at three locations; each location forming the apices of a triangle approximately one mile distant from each other. Unfortunately the detailed bedrock geology is obscured by surficial materials at the point of issue for each spring. At Sand Spring itself the thermal water with a temperature of 24°C (76°F) flow may be along the contact of Cambrian quartzite thrust over Ordovician limestone (Fig. 8). The remaining two springs appear to issue from a

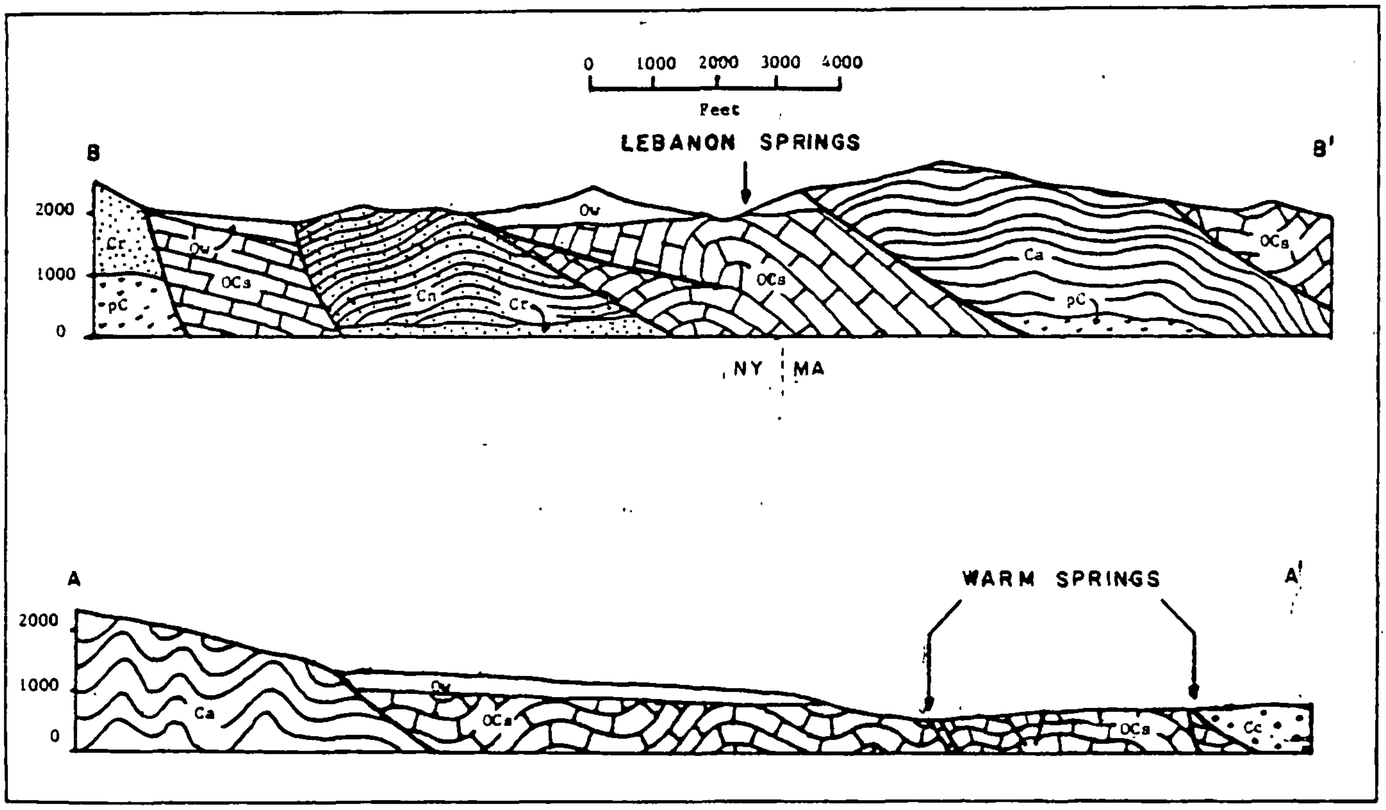

FIGURE 8: Geological cross sections in western Massachusetts. Section locations shown on Figure 9B. Section A-A' shows the warm springs at Williamstown, MA, are associated with high angle reverse faults involving the Cambro-Ordovician Stockbridge group (OCs) and the Cambrian Cheshire formation (Cc). Section B-B' shows the Lebanon Springs emerging at the contact of the Ordovician Wallomsac formation (Ow) and the Stockbridge group after ascending on the thrust fault about 1000' to the southeast. (Modified from NYSERDA Report 81-4 prepared by Dunn Geoscience Corporation).

fault zone within the Ordovician dolomite. The water temperatures were recorded as 19.5°C (67°F) for the northern and 20°C (68°F) for the southern spring. Since the geothermal gradients in the vicinity of Williamstown are not elevated it would appear that deep circulation of ground water is the source of the heated waters.

Hansen et al. (1974) have analyzed the waters from wells at Sand Springs (Table 2). The warm waters are represented by analyses S'2, S'2a and S'8. It is obvious that there exists a direct correlation between temperature and SiO_2 content, suggesting that the waters of Sand Spring probably attain a higher temperature at depth. The flow rate at the springs is approximately 24,000 gallons per hour (Waring, 1965).

The New York State Energy Research and Development Authority report (1981) prepared by Dunn Geoscience Corporation gives the results of a survey of water chemistry, temperature and measured gradients, which included a portion of western Massachusetts and southwestern Vermont. The silica contents and measured water temperatures at the surface are given in Table 3, and locations on Figure 9.

The feasibility of utilizing the thermal waters of Sand Spring for domestic heating purposes appear to be good. The water quality is excellent; the water temperature is approximately 14°C above that of normal ground water and the flow rate (400 gal/min) more than adequate.

Some geothermal gradients in western Massachusetts and southwestern Vermont are abnormally high and increase into eastern New York. The background geothermal gradient appears to fall in the range of 5 - 7°C/km. The abnormally high gradients (Figure 9, Table 4) form a north-northeast trending zone extending from Lebanon Springs New York to the vicinity of Pownal, Vermont, and range up to four times the

TABLE 2

CHEMICAL ANALYSES OF SPRINGS IN WILLIAMSTOWN, MASSACHUSETTS

Local Well #	S2	S2a	S3	S6	S7	S8	S9
Temp. °C	21.0	22.0	11.0	8.1	22.0	17.8	8.9
SiO_2 (mg/l)	13.0	12.0	0.5	4.2	12.0	7.2	0.6
Fe (ug/l)	20.0	20.0	10.0	--	20.0	20.0	10.0
Mn (ug/l)	0	0	0	--	0	0	0
Ca (mg/l)	21.0	23.0	24.0	18.0	25.0	46.0	36.0
Mg (mg/l)	11.0	8.8	4.2	3.0	8.9	11.0	11.0
Na (mg/l)	3.3	2.0	1.3	0.3	2.0	1.9	1.9
K (mg/l)	1.3	0.9	0.2	0.1	0.9	0.6	0.8
HCO_3 (mg/l)	116.0	118.0	84.0	68.0	114.0	177.0	154.0
CO_3 (mg/l)	0	0	0	0	0	0	0
SO_4 (mg/l)	8.6	8.1	7.5	6.0	8.1	11.0	6.5
Cl (mg/l)	2.0	1.0	0.4	0.1	1.3	0.8	0.6
F (mg/l)	0.1	0.1	0.2	0.0	0.1	0.1	0.2
NO_3 (mg/l)	0.4	1.0	1.0	4.2	0.4	0.7	1.1
pH	8.2	7.8	7.7	7.7	8.1	8.0	8.1

From Hansen et al., 1974

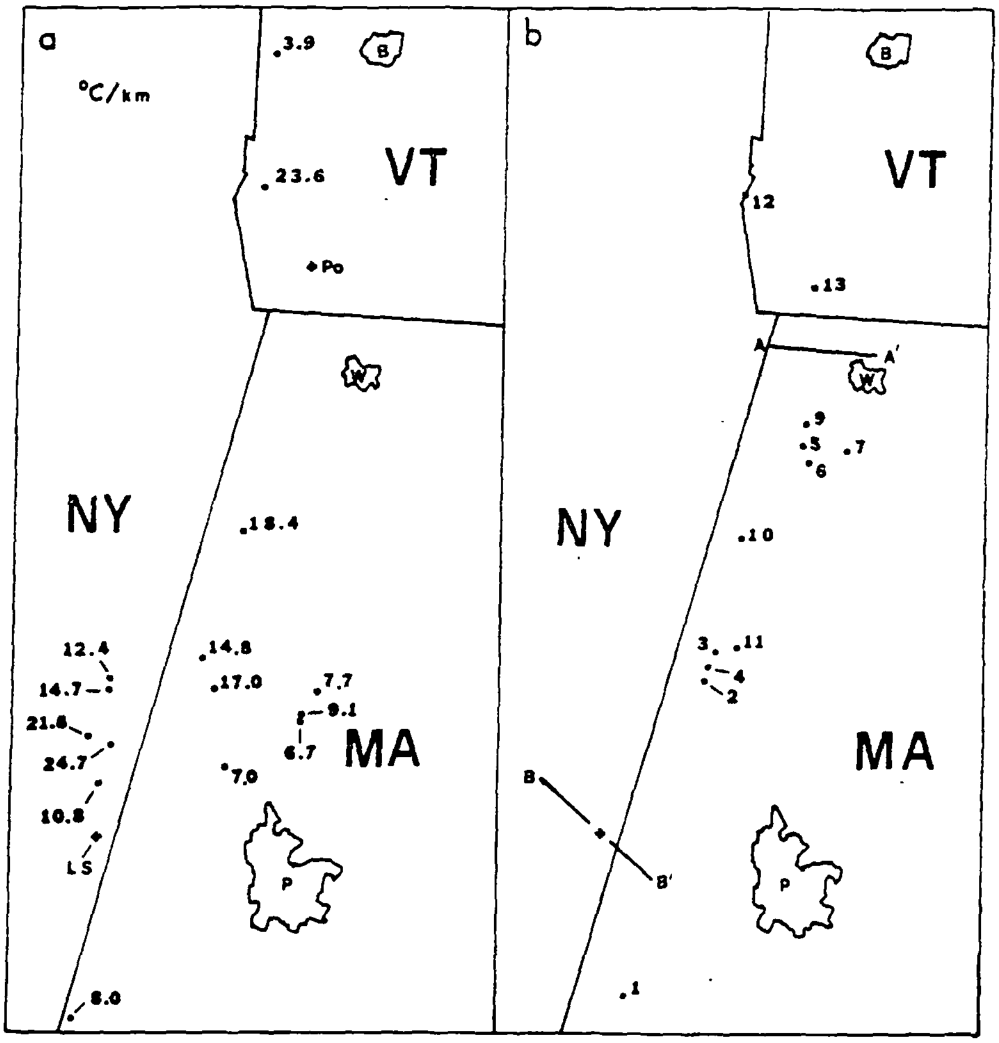

FIGURE 9: a) Geothermal gradients (°C/km) in western Massachusetts, New York and Vermont. Communities shown are: B = Burlington, VT., PO = Pownal, VT., W = Williamstown, MA, P = Pittsfield, MA, and LS = Lebanon Springs, NY.

b) Location of wells listed in Table 3. The cross-sections in Figure 8 are located near Williamstown (A-A') and Lebanon Springs (B-B'). (Modified from NYSERDA Report 81-4 prepared by Dunn Geoscience Corporation.)

TABLE 3

SILICA CONTENTS AND WATER TEMPERATURES

Western Massachusetts and S. W. Vermont

Sample Number	NAME	Silica ppm	T(^{o}C)	LOCATION
MASSACHUSETTS:				
1	Shyffer	5.9	7.2	Deerhill Rd., Richmond, MA.
2	Leab	5.6	11.9	Rt. 43, Hancock, MA.
3	Monette	5.7	11.8	Rt. 43, Hancock, MA.
4	Fenander	5.3		Rt. 43, Hancock, MA.
5	Locke	6.1	8.3	Oblong Road, Williamstown, MA.
6	Greylock H. S.	6.7		Williamstown, MA.
7	Mt. Hope Farm	6.3		Williamstown, MA.
8	Rhodes	5.5		Hancock Road, Williamstown, MA.
9	White	6.1		Oblong Road, Williamstown, MA.
10	Jericho Valley Motel	5.2		Rt. 43, Hancock, MA.
11	Hamilton	4.2		Hancock, MA.
VERMONT:				
12	Sheldon	6.5	10.3	Rt. 396, NY/VT border
13	Gen. Cable	9.2		Rt. 396, N. Pownal, VT.

TABLE 4

TEMPERATURE GRADIENTS

Eastern New York and Adjacent Vermont and Massachusetts

LOCATION	DEPTH (METERS)	GRADIENT (^{o}C/km)
Pownal, VT.	220	23.63
Hancock, MA.	140	14.82
Hancock, MA.	155	17,03
Rt. 43 & Rt. 22, Stephentown, N. Y.	145	14.72
Stephentown Center, N. Y.	185	21.60
Rt. 43, Hancock, MA.	130	18.36
Wyomack Road, South Stephentown, N. Y.	160	24.68
West Road, Lebanon Springs, N. Y.	80	10.83
Saltbox Farm Road, Hancock, MA.	190	7.72
Bailey Road, Hancock, MA.	260	9.06
Bailey Road, Hancock, MA.	125	6.73
Churchill Road, Pittsfield, MA.	160	7.01
Off Rt. 22, Stephentown, N. Y.	80	12.40
Vt. Route 9, Bennington, VT.	105	3.86
West Road, West Richmond, MA.	185	7.95

apparent normal gradient (from 6.7 to 23.6° C/km.). However no additional thermal springs and no wells pumping heated waters have been located.

New England Water Well Temperatures

Since most of the consumptive water supplies in New England are derived from surface storage reservoirs and the bulk of the ground water contribution to that supply is derived from unconsolidated glacial sediments, only a small fraction comes from wells driven to bedrock. Although the rocks of the region are highly fractured and faulted, water wells intersect only a minute fraction of these structures and therefore provide a very small sampling of the fluids possibly circulating within them.

Water temperatures from bedrock wells range from 6°C (41°F) at Presque Isle, Maine from a 94m (310') well to 19°C (67°F) at Somerset, Massachusetts, from a 457m (1500') well (Table 5). Most water temperatures fall below 13°C (55°F) and in Massachusetts, which contains the largest number of drilled wells, the average temperature is 11.4°C (Table 6).

Specific Regions of Initial Interest

Based upon geological and geophysical studies certain areas in New England were considered to have the highest potential for the possible existence of hydrothermal geothermal resources. These included the White Mountains region of central New Hampshire, the Narragansett Basin of Massachusetts and Rhode Island, the Connecticut River Valley extending from Connecticut north into Vermont, and the overthrust belt of western Massa-

TABLE 5

Partial Chemical Analyses in ppm of Waters from Selected Wells in New England Bedrock

Location	Depth (m)	Source Rock	T(°C)	SiO_2	Ca	Mg	Na	K
MASSACHUSETTS:								
Abington	15	Gneiss	7.2	9.6	12	3.3	8.8	1.2
Brockton	31	Gneiss	7.8	11	22	5.3	4.9	.6
Duxbury	33	Gneiss	8.9	5.3	8.4	2.0	4.1	1.4
E. Bridgewater	25	Gneiss	11.1	17	16	8.4	8.3	1.0
Taunton	64	Argillite	11.7	24	15	2.5	14.0	1.1
Mattapoisett	?	Argillite	9.4	25	37	9.1	11.0	3.7
Lynnfield	180	Schist	7.8	17	14	5.0	7.3	1.2
Wilmington	125	Schist	9.5	11	23	5.8	13.1	1.9
Middleborough	?	?	9.4	11	3.2	2.0	5.8	.5
Adams	146	Quartzite	10.8	17	6.6	1.4	1.1	.3
Windsor	45	Gneiss	9.7	13	16	6.2	5.3	.7
Charlemont	77	Gneiss	9.4	15	9	5.7	4.2	.4
Goshen	32	Gneiss	9.5	12	10	6.8	5.0	.6
Bernardston	?	Gneiss	9.8	17	13	7.2	6.1	1.1
Hardwick	61	Gneiss	10.1	21	11	6.2	7.3	.9
Belchertown	56	Gneiss	10.6	18	14	5.2	4.1	.6
Easthampton	143	Triassic	12.3	21	29	2.6	4.2	.5
Florence	92	Triassic	11.9	25	31	4.3	3.0	.5
Hatfield	?	Triassic	12.6	31	27	5.2	4.6	.7
Barre	?	Gneiss	10.1	14	7	5.8	3.6	1.1
Boxford	?	Gneiss	10.0	8	17	4.8	8.0	1.8
Georgetown	?	Gneiss	10.0	15	22	9.0	14.0	1.5
Newbury	37	Gneiss	11.1	13	13	4.4	59.0	2.2
Egermont	30	Limestone	10.0	6.9	0.2	0.1	103.0	0.2
Washington	15	Gneiss	13.3	12	22	7.4	2.5	4.9
Williamstown	113	Limestone	8.9	6.6	23	13	1.1	0.7
Gill	40	Sandstone	13.3	11.0	24	15	4.3	1.1
Chicopee	34	Shale	12.8	15.	96	19	18	1.5

Location	Depth (m)	Source Rock	T(°C)	SiO_2	Ca	Mg	Na	K
CONNECTICUT:								
Granby	100	Triassic	12	12	8.1	1.1	39.0	.6
Simsbury	91	Gneiss	10.5	12	8.5	1.9	2.1	.6
Avon	31	Triassic	12.2	13	19	1.8	3.5	.4
Avon	26.5	Gneiss	10.4	10	5.7	1.6	2.2	.4
Framingham		Triassic	12.8	24	26	9.3	6.0	.5
Framingham	132	Triassic	10.5	16	17	1.3	20.0	.8
Framingham	107	Triassic	12.2	13	31	5.3	3.7	.6
Bristol	46	Gneiss	11.6	27	17	7.8	6.7	1.4
Southington	130	Triassic	10	24	35	3.6	5.5	3.6
Plainville	67	Triassic	12.8	20	31	7.9	4.6	1.4
Bloomfield	185	Triassic	11	17	28	15	7.8	1.1
Glastonbury	76	Gneiss	12.8	15	6.3	1.3	3.6	1.7
Manchester	183	Triassic	12.8	14	27	10	2.3	.8
Portland	36	Gneiss	11.	12	33	5.3	9.1	1.9
MAINE:								
Presque Isle	94	Limestone	6	8.5	7.4	14	6.0	.5
Raymond	181	Granite	6.5	16	27	4.6	8.4	.6
Vassalboro	76	Schist	10.5	13	29	9.7	3.5	3.6
Charlestown	72	Schist	9.8	8.4	26	9.5	-	-
Newport	37	Limestone	9.8	8.5	73	7.0	2.3	.5
Monson	96	Slate	9.6	-	4.8	1.6	3.7	1.4
Bucks Harbor	52	Rhyolite	10.7	14	35	3.8	-	-
North Berwick	84	Schist	9.8	13	23	3.1	8.2	3.1
VERMONT:								
Bennington	42	Gneiss	9.7	14	8.2	5.3	6.9	.7
West Dover	26	Gneiss	9.9	16	13	9.6	4.4	.5
Newfane	35	Gneiss	8.9	11	21	5.1	3.9	.6
Chester	14	Serpentine	8.3	13	7	14.2	2.1	.4
Danby	21	Marble	9.4	9	29	13.	3.4	.8
Ludlow	11	Schist	9.1	14	11	6.2	4.5	1.2
Hartland	13	Schist	9.2	15	17	8.1	3.1	.6
Rutland	22	Schist	9.4	17	19	7.2	4.7	1
Pittsfield	15	Gneiss(?)	10.6	19	11	7.9	6.3	.8
Barre	22	Granite	7.8	21	9	4.7	7.2	3.1

TABLE 6

Water Temperatures from Selected Bedrock Wells of Massachusetts

LOCATION	DEPTH (m)	TEMPERATURE (^{o}C)
Western Massachusetts:		
Dalton	194	7.8
Dalton	156	10
Dalton	58	10
Great Barrington	156	10.6
Lee	196	10
New Marlborough	9	7.2
Pittsfield	193	7.8
Stockbridge	75	9.4
Williamstown	152	12.8
Williamstown	113	8.9
Greenfield	47	9.4
Chicopee	138	8.9
Chicopee	155	13.3
Chicopee	246	13.9
Chicopee	215	9.4
Springfield	160	9.5
Springfield	105	10
Southeastern Massachusetts:		
Acushnet	30	14.4
Easton	64	12.8
New Bedford	7	10
New Bedford	15	15.6
New Bedford	12	10.1
New Bedford	4	12.2
North Attleboro	152	12.2
North Attleboro	105	7.2
Rehoboth	30	13.3

LOCATION	DEPTH (m)	TEMPERATURE (°C)
Rehoboth	35	11.1
Rehoboth	34	12.2
Rehoboth	49	13.3
Rehoboth	93	10.6
Rehoboth	12	13.4
Seekonk	40	13.8
Swansea	60	13.9
Swansea	29	12.6
Somerset	457	17
Somerset	305	19
Taunton	154	13.7
Taunton	19	12.1
Taunton	154	12.2
Taunton	64	12.0
Northeastern Massachusetts:		
Boxford	56	11.0
Chelmsford	22	12.2
Dracut	53	12.3
Lowell	46	12.7
Newbury	59	9.3
Newbury	37	11.2

chusetts and Vermont. While no potential resource can be postulated for any of these regions as a result of this study a discussion of each is given herein to explain their selection.

The White Mountain Region

There has been much speculation over the past few years concerning the possibility of there being moderately high temperatures at depth within certain plutons that are a part of the White Mountain Magma Series. The relatively young plutons range in age from 110 to 182 m.y. (Tilton and Davis, 1951; Folard, 1970). Billings and his students (Billings, 1928; Billings and Williams, 1935; Henderson, 1949; Moke, 1946; Smith and others, 1940) delineated eight plutonic rocks of differing composition, which are considered to be consanguineous. Billings (1945) concluded that the intrusives were emplaced by cauldron subsidence and stoping. Geophysical studies on the Merrymaking stock in New Hampshire (Griscom and Bromery, 1968) support the suggestion of Chapman (1968) that the plutons represent cumulates and that they crystallized as floored intrusions with mafic rocks at depth.

The White Mountain Magma Series is composed of a group of plutonic and volcanic rocks that range in composition from gabbro to syenite. Of these, biotite granites near Conway and Waterville, New Hampshire, give the highest heat flow values (1.95 to 2.21 HFU - see Figure 7) of any so far determined in New England. The high heat flow is attributed by Birch et al. (1968) to the abnormally high concentrations of uranium, thorium and potassium contained in the granites. Osberg et al. (1978) have determined that the concentration of radioactive elements is fixed in allanite, huttonite, thorite and zircon, and dispersed in biotite, feldspar and quartz.

Birch et al. (1968), apparently using simple assumptions about the shape of the plutons and the distribution of the radioactive elements, calculated that the surface heat flow could be generated in plutons 6 to 10 km thick and would reach temperatures of 150° to 200°C at depths of between 4 and 5 km. Osberg et al. (1978) concluded from detailed gravity studies that the Conway granite is between 4 and 5.25 km thick. They further conclude from temperature modeling that the high heat flow which Birch et al. (1968) attributed to being derived primarily from concentrations of radioactive elements in the granites is open to question. Osberg contoured the heat flow values and suggests the existence of a north northeast trending ridge of high surface heat flow which he interprets to represent a "bump" in background heat flow. He suggests that the heat flow entering the crust at 10 km depth is larger (1.3 HFU) than elsewhere in New England (the 0.8 HFU value of Birch). Using the higher value for heat entering the upper crust they derived a temperature distribution model giving temperatures of 76° to 110°C at 5 km and 93° to 135°C at 5.25 km.

The Osberg study therefore suggests only minor temperature increases within and beneath the Conway and related granites. Field observations and literature search of the region yield no evidence of any springs or ground waters of even slightly elevated temperatures. Thus it appears unlikely that there is any potential for low temperature hydrothermal geothermal resources associated with the plutons of the White Mountain Magma Series.

The Narragansett Basin

Lyons and Chase (1976) report that the carboniferous rocks of the

Narragansett Basin (Figure 2, Plate I) are predominently conglomerate, arkose, graywacke, siltstone and shale with some coal. Only rough estimates of the total thickness of the sedimentary sequence are possible due to the scarcity of outcrop, rapid facies changes and structural complexities. The thickness probably lies between 2000 and 12000 feet. Mutch (1968) concluded that the region was an isolated inter-montane basin characterized by rapid deposition of various types of fluvatile sediments. He also believes the total thickness of the sequence to be close to 12000 feet. The more pelitic sediments have been metamorphosed to slate and phyllite and the metamorphic grade increases southward to staurolite grade in parts of southern Rhode Island. The sedimentary rocks are highly indurated and the permeability quite low. Frimpter and Maevsky (1979) report that in many core samples from test borings healed and unhealed fractures and slickenside surfaces were common, indicating that these rocks had undergone brittle deformation. Where the fractures are open ground water occurs under pressure, but yields are low. During 1977 the U.S.G.S. conducted pump tests on twelve observation wells and yields ranged from 0.36 to 30 gal/min with very slow recovery after pumping was stopped in all but one case. Four wells yielded water with temperatures above the normal 10 - 11°C ground water temperatures in the Basin. Two wells at Bristol, Rhode Island, both yielded water with the temperature at 15°C (59°F), and the water remained salty throughout the pump test. Two wells at Somerset, Massachusetts, one 1000 feet and the other 1500 feet deep, gave very low yields of water at 17°C (63°F) and 19°C (67°F) respectfully. The deeper well is located about 100 feet from the shore of Narragansett Bay and the specific conductance of the water rose from 510 to 880 during a three hour pump test indicating salt water inflow into the well. The elevated temperatures in the Somerset wells are probably caused by inflow of discharge from the nearby Brayton Point New England Power plant.

The Connecticut Valley

The present day Connecticut Valley is a topographic low developed by the erosion of Mesozoic age detrital sedimentary rocks. Geologically it is an asymmetrical structural trough or elongate basin that is fault-bounded on the eastern margin (Fig. 10). The development of the trough was controlled by physical differences in the underlying Paleozoic metamorphic rocks. The north-south trend follows zones of weakness defined by the low grade metamorphic rocks of the Connecticut Valley-Gaspe synclinorium, which separate the zones of mantled gneiss domes of the Berkshires to the west from the domes of the Bronson Hill Anticlinorium to the east. The geometry of the edges of the basin is influenced by local basement structures, especially the dipping flanks of the domes.

The Mesozoic age basin is divided into two sub-basins to the north and south of Amherst, Massachusetts. The northern portion, known as the Deerfield Basin, contains less than 1 km of detrital sediments and volcanics. The southern and more extensive part of the structural feature is known as the Hartford Basin, which extends south from Amherst to Long Island Sound. The thickness of Mesozoic age rocks exceeds 4 km under Springfield, Massachusetts. The two basins are separated as the result of a large intrusion of tonalite of Devonian age (the Belchertown Complex) that cuts across the rocks of the Connecticut Valley-Gaspe Synclinorium and into the west flank of the Bronson Hill Anticlinorium thus disrupting the north-south zones of structural weakness between the two

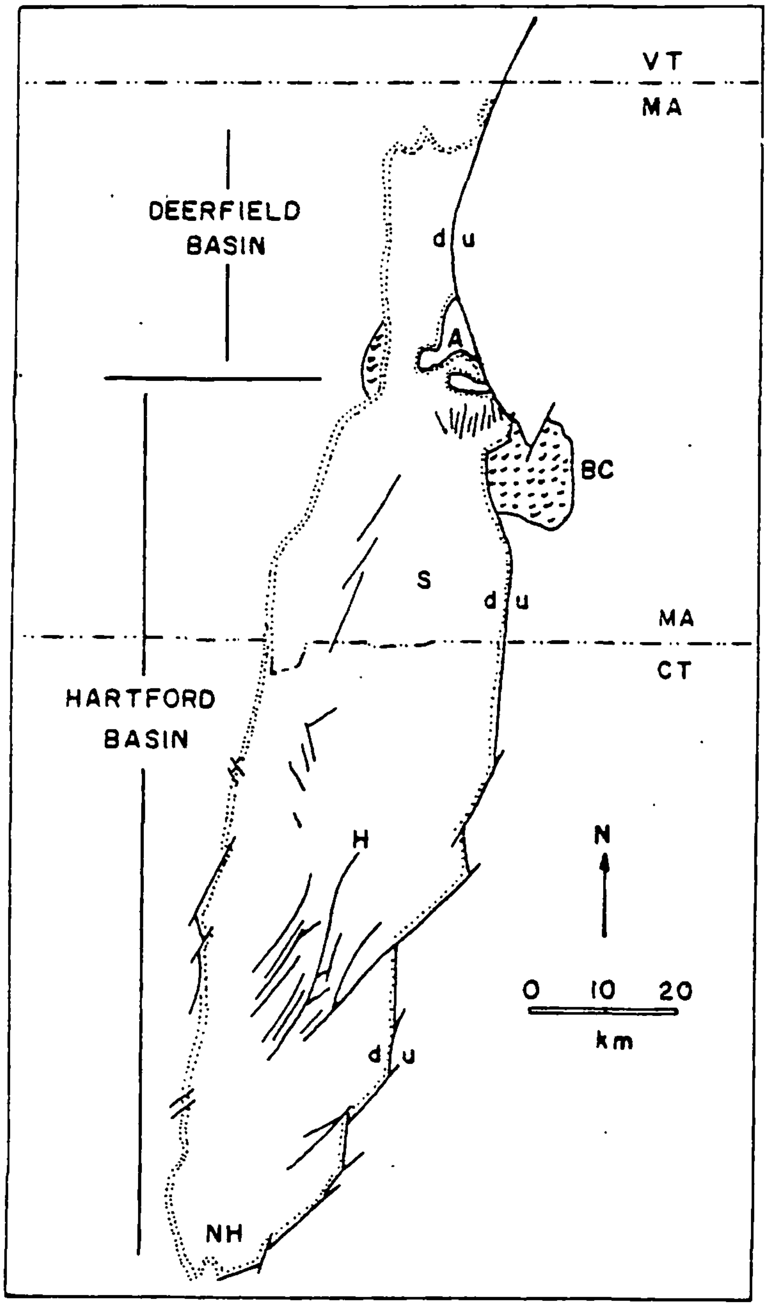

FIGURE 10: The Mesozoic Basin of the Connecticut River Valley is fault controlled on the eastern margin, and divided into two sub-basins separated by the Devonian age Belchertown intrusive complex (BC). Cities located are Amherst (A) and Springfield (S), Massachusetts and Hartford (H) and New Haven (NH), Connecticut. The western edge of the basin is an erosional contact denoted by the double dotted line.

belts. Subsidence of the two basins was greatest on the eastern side along a westerly dipping listric fault system so the general dip of the Mesozoic rocks is to the east.

Wise (1979) and his students have been conducting detailed studies of the structures related to the basins and a number of patterns have emerged. They show that a trend of N30-40°E extensional structures dominates the region, especially within and east of the basins. These structures are represented by basalt dikes, veins, joint sets and normal faults. They conclude that much of the eastern border fault zone of the basins is composed of segments of faults of this type. In areas where the trend of the basin parallels the structural N30-40E trend the movement on the faults is dip slip, the trend is interpreted as being the regional extension direction during the early to middle stages of basin formation. Late stage movements on the faults controlling the basin appear to be of a strike-slip nature as indicated by slickensides on the fracture and fault planes.

Portions of the Belchertown intrusive complex contain an unusual amount of allanite, a member of the epidote group containing up to 3% thorium and rare earths. It was thought that the heat provided by radioactive element decay might be trapped by the overlying Triassic-Jurassic sedimentary rocks and provide a heat source for any deep circulating waters. Unfortunately the distribution of allanite is quite sporadic, and the principal concentration is found in that part of the complex which lies on the west side of the structural basin and is covered by only a thin veneer of sedimentary rocks. There are no known water wells in the area which penetrate into bedrock, since most of the valley region between the exposures of the complex to the east and west is mantled by a thick cover of glacial sediments.

The faults that bound the basin on the east side of the Connecticut River Valley are thoroughly cemented, show no evidence of any movement in historic time and are aseismic. Wells that do penetrate into the Triassic-Jurassic rocks show no evidence of elevated temperatures (see Table 5). One well, in Hadley, Massachusetts, was reported (Gruy Federal, personal communication) to be 250 feet deep and yielding water at 15.6°C (60°), but attempts to locate the well failed. This well, and all wells in Hadley, would overly the buried Belchertown complex but are completed in glacial sediment. All town wells are 70 feet deep or less and do not exceed 11°C (52°F).

The St. Johnsbury Thermal Anomaly

During the course of field investigation an unusual thermal anomaly was discovered in the town of St. Johnsbury in northeastern Vermont.

The town is underlain by Siluro-Devonian schists which are mantled with thick ice-contact glacial sediments forming broad terraces. The owner of the residence at 115 Main Street reported a small roughly circular area of about 15 feet diameter next to the house upon which snow would melt and only moss would grow, and further that this occurrence had been noted in diaries of former occupants in the 19th century.

During April and May, 1981, several visits to the site were made, and a series of auger holes drilled to lengths up to 8 feet. A probe recorded temperatures varying from 96°F to 105°F. The material in which the holes were drilled is a clean, dry sand. The following is an exerpt from a letter dated June 28, 1981 from the property owner.

> "In the afternoon I noticed again what I have noticed in the past, a slight gassy smell coming from the hole. Thinking it might be swamp gas in small quantity I eventually decided to try lighting it with a match, so at 5:15 p.m. I did so, and the hole burst into flame and kept on burning. Since there are now five holes in the hot area, I tried them all with matches and all burst into flame, though none as powerfully as the new hole. I should have done this last summer for I recall the gassy smell when I dug a hole with a shovel in the hot area."

The local utilities company has no record of any gas line in the area.

The source of the gas and the heat remains unexplained.

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