Conf-8210125
UC66, UC66a through
UC66j

CONF-8210125-Suppl.-13

CONF-8210125--Suppl.

DE83 009736

# GEOTHERMAL PROGRESS MONITOR

## Special Supplement

Proceedings of the Geothermal Program Review
October 25-26, 1982
Washington, D.C.

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**U.S. Department of Energy**
Assistant Secretary for Conservation and Renewable Energy
Division of Geothermal and Hydropower Technologies
Washington, D.C. 20585

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APPENDIX L - Presentation 13

Topic: Geoscience Technology

Speaker: Mike Wright (UURI)

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Presentation by

Earth Science Laboratory

University of Utah Research Institute

for

Geothermal Status Review Meeting

25 Oct. 1982

Washington, D.C.

L-3,4-4

The Earth Science Laboratory of UURI has contributed substantially to development of new techniques and testing of available techniques for geothermal exploration and resource evaluation. In addition, UURI has provided technical management assistance to DOE/ID, DOE/NV and DOE/SAN for about $45 million in DOE geothermal programs and has been an active participant in numerous DOE planning efforts. These accomplishments are summarized on the first three figures.

The Industry Coupled Program provides cost sharing to industry for geothermal exploration. Projects have been funded in Utah and Nevada. UURI's role is to interpret data generated by these projects, to publish reports on the interpretations and to open file the data. The next three figures summarize results from this program. Successful wells were drilled at Beowawe and Dixie Valley under this program for a success ratio of 13%, which probably represents an industry average for wildcat drilling in fairly well known geothermal environments.

The State Coupled Program provides funding for teams of geoscientists in 18 western states to assess their low- and moderate-temperature geothermal resource base and to publish maps. UURI's role is in coordination of the state teams to ensure work along programmatic lines and cooperation among the state teams, NOAA (who publishes most of the maps) and the USGS (who receives data generated). The figure gives the current status of map publication.

In the Exploration and Assessment Technology Program, UURI has provided technical assistance to DOE/ID in managing contract research and, more importantly, has conducted research of its own. The figures show the outside research contacts funded under this program.

UURI research has concentrated mostly on geochemical and geophysical topics with a similar but smaller program in geological research. In geophysics UURI has developed highly successful computer-based interpretation techniques for application to the electrical methods commonly used in geothermal work, namely galvanic resistivity, magnetotellurics (MT) and audiomagnetotellurics (AMT). UURI has published catalogs of models for use by geophysicists interpreting such data and have also published entire computer programs that others can use in data interpretation. A summary is given in the figures.

UURI's geochemical research has been highly successful. Techniques for using the measured distribution of trace elements to construct a picture of zoning around a geothermal heat source have been developed and are now being adapted by industry. One figure shows how the distribution of mercury in drill holes mimics the observed temperature distribution. Observation of mercury distributions in holes in real time while drilling can help determine whether one is approaching a higher temperature resource.

UURI has also worked on modeling of fluid/rock interaction in a geothermal reservoir. This assists in predicting mineral distribution expected in fractures so that identification of these minerals in drill cuttings can be used to help locate fractures. In addition, UURI has developed methods of determining actual reservoir fluid chemistry from observation of the compositions of the fluids and gasses at the well head. This is important because good down-hole samples are very difficult to obtain. A figure shows the calculated reservoir composition for well 14-2 at Roosevelt Hot Springs and the following figure shows the percentage of dilution by meteoric water for several wells at Roosevelt. The next figure

shows calculated mineral equilibria as a function of temperature. This type of modeling can be useful in interpreting observed mineral assemblage such as the work done by Wilf Elders at UC-Riverside.

# EARTH SCIENCE LABORATORY




## UNIVERSITY of UTAH RESEARCH INSTITUTE

## SALT LAKE CITY, UTAH

# MAJOR ACCOMPLISHMENTS
# ESL AND UU

★ HIGH QUALITY GEOLOGIC MAPPING IN 10 HIGH TEMPERATURE AREAS

- LITHOLOGY, STRUCTURE, HYDROTHERMAL ALTERATION
- CONCEPTUAL MODELS/EXPLORATION STRATEGY

★ TRACE ELEMENT GEOCHEMICAL TECHNIQUES DEVELOPED AND TESTED

- SYSTEM-SCALE ZONING - SITING DRILL HOLES
- SMALL-SCALE ZONING - FRACTURES/FLUID ENTRIES: COMPLETION DECISIONS
- DISTRIBUTION OF PERMEABLE FAULTS & AQUIFERS

TECHNIQUES NOW IN USE BY INDUSTRY

★ GEOCHEMICAL MODELING PROGRAMS IMPLEMENTED FOR FLUID/ROCK INTERACTION

- PREDICT DISTRIBUTION OF HYDROTHERMAL MINERALS
- USE IN EXPLORATION, RESERVOIR STUDIES, WELL COMPLETION DECISIONS

★ UNIQUE GEOPHYSICAL MODELING TECHNIQUES DEVELOPED

- 3D RESISTIVITY, MAGNETOTELLURICS, EM
- SELF POTENTIAL INTERPRETATION
- BOREHOLE GEOPHYSICS INTERPRETATION
- NOISE ANALYSIS AND SIMULATION
- COMPUTER PROGRAMS PUBLISHED FOR 10 INTERPRETATION METHODS - 312 COPIES DISTRIBUTED

★ ROOSEVELT HOT SPRINGS ESTABLISHED AS VALUABLE TEST AREA FOR EXPLORATION AND RESERVOIR EVALUATION TECHNIQUES

★ COST EFFECTIVE EXPLORATION ARCHITECTURE DEFINED FOR BASIN AND RANGE

- EXPLORATION AND RESOURCE ASSESSMENT TECHNIQUES EVALUATED

# MAJOR ACCOMPLISHMENTS
# ESL

★ USER COUPLED CONFIRMATION DRILLING PROGRAM
- CONCEIVED, PROPOSED, IMPLEMENTED
- TECHNICAL ASSISTANCE TO DOE (WITH EG&G)

★ MICROEARTHQUAKE NET INSTALLED AND OPERATED AT ROOSEVELT AND RAFT RIVER
- MAJOR EARTHQUAKE SWARM AT ROOSEVELT

★ TECHNOLOGY TRANSFER PROGRAM
- 200 TOTAL REQUESTS FULFILLED
- INJECTION RESEARCH INIATED AT RAFT RIVER IN COOPERATION WITH EG&G

★ GEOTHERMAL SAMPLE LIBRARY OPERATIONAL
- 2,100m CORE
- 80,000m CUTTINGS
- 22 GEOTHERMAL AREAS

★ MAJOR CONTRIBUTIONS TO GEOTHERMAL GEOSCIENCE
- 66 REPORTS
- 63 PAPERS AT PROFESSIONAL MEETINGS
- 54 JOURNAL PUBLICATIONS
- 5 WORKSHOPS

# MAJOR ACCOMPLISHMENTS

## ESL

★ MANAGEMENT AND TECHNICAL ASSISTANCE FOR $45M IN DOE-FUNDED PROGRAMS (TO FY82)

★ MOST SIGNIFICANT COOPERATIVE EFFORT EVER BETWEEN GOVERMENT & INDUSTRY FOR U.S. RESOURCE EVALUATION

- INDUSTRY COUPLED PROGRAM
- $32M OF PROSPECT DATA IN PUBLIC DOMAIN
- GEOSCIENCE WORK AND REPORTS IN 13 MAJOR GEOTHERMAL AREAS

★ MANAGEMENT & TECHNICAL ASSISTANCE TO DOE & USGS IN LOW- & MOD- TEMP RESOURCE ASSESSMENT

- STATE COUPLED PROGRAM IN 17 WESTERN STATES
- ASSISTANCE IN USGS CIRC 790 AND FORTHCOMING UPDATE

★ PLANNING CONTRIBUTIONS

- EXPLORATION AND ASSESSMENT TECHNOLOGY PROGRAM
- USER COUPLED DRILLING PROGRAM PLAN
- M-X/RES GEOTHERMAL PLAN
- INPUT TO:
  - √ RMB & R Commercialization Plan
  - √ RMB & R Market Penetration Plan
  - √ Market Shares Estimates Studies
  - √ Natural Direct Heat Program Plan
  - √ ERAB Panel
  - √ USFS RARE II Studies
  - √ BLM Wilderness Studies
  - √ National Geothermal Progress Monitor

# INDUSTRY COUPLED PROGRAM

- OPERATED BETWEEN FY-78 and FY-82
- TOTAL PROGRAM COST $34M
- SUPPORTED INDUSTRY EXPLORATION IN:

| NEVADA | UTAH |
|---|---|
| *Baltazor* | *Cove Fort - Sulphurdale* |
| *Beowawe* | *Roosevelt Hot Springs* |
| *Colado* | |
| *Desert Peak* | |
| *Dixie Valley* | |
| *Humboldt House* | |
| *Leach Hot Springs* | |
| *McCoy* | |
| *San Emidio* | |
| *Soda Lake* | |
| *Tuscarora* | |

- COMPANIES INVOLVED

| | |
|---|---|
| *AMAX* | *GETTY* |
| *AMINOIL* | *PHILLIPS* |
| *CHEVRON* | *SOUTHLAND ROYALTY* |
| *EARTH POWER PRODUCTION* | *THERMAL POWER* |
| *GEOTHERMAL POWER* | *UNION* |

# SUMMARY OF TECHNIQUES USED BY INDUSTRY
# DOE / DGE CASE STUDY PROGRAM

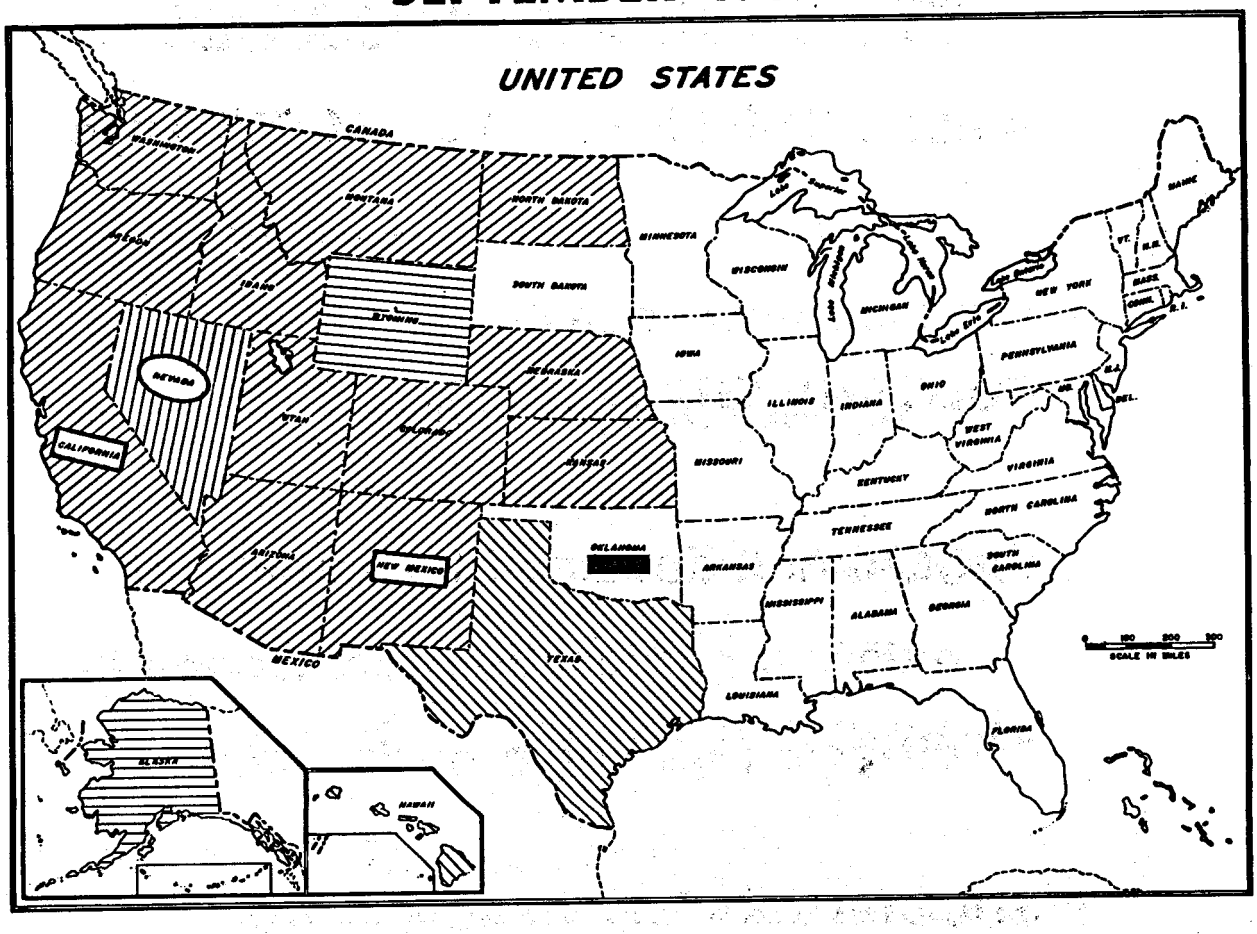
| METHOD | PERCENT OF CASES EMPLOYED | PRIORITY |
|---|---|---|
| SHALLOW THERMAL GRADIENT (100m) | 71 | 1 |
| DEEP THERMAL GRADIENT (600m) | 71 | 1 |
| MAGNETOTELLURIC (MT) | 71 | 1 |
| GRAVITY | 71 | 1 |
| MAGNETICS | 57 | 2 |
| GEOLOGIC MAPPING | 50 | 3 |
| ELECTRICAL RESISTIVITY | 50 | 3 |
| PASSIVE SEISMIC | 43 | 4 |
| ACTIVE SEISMIC | 43 | 4 |
| GEOCHEMISTRY | 29 | 5 |
| SELF POTENTIAL | 29 | 5 |

# INDUSTRY COUPLED PROGRAM

| | |
|---|---|
| WELLS DRILLED | 15 PRODUCTION |
| | 5 DEEP ΔT |
| FOOTAGE DRILLED | 125,000 |
| PROGRAM COST | $34,000K |
| PRODUCTIVE WELLS | 2 |
| SUCCESS RATIO | 0.13 |

# STATE COUPLED PROGRAM MAP STATUS

## SEPTEMBER 1982




- User Map Published or in press (NOAA)
- State Printed Map
- User Proof in Review
- User Map in preparation
- Update in preparation
- Technical Map in Production
- Other Map Through State Program



SC-046

# EXPLORATION AND ASSESSMENT TECHNOLOGY PROGRAM

- Develop new techniques for exploring geothermal systems
- Assess and document the utility of existing exploration techniques in different geologic environments
- Transfer this knowledge to the geothermal industry

# OUTSIDE CONTRACTS: FY 1979

| | | |
|---|---|---|
| 1. Borehole Geophysics | Univ. Southern Cal. | $87,868 |
| 2. Multiple Geophysical Data Set Analysis | $S^3$ | $89,450 |
| | ERIM | $94,288 |
| 3. Geothermal Earth System Models | International Engineering Co. | $75,500 |
| 4. Geochemical Detection of Hydrothermal Systems | Barringer Research | $94,430 |
| | Earth Sciences Inc. | $70,475 |
| 5. 3-D Inverse Electrical Methods | LuTech Inc. | $64,528 |
| 6. 3-D Topographic Effects | Univ. New Mexico | $54,970 |
| 7. Enhancement of Signal to Noise Ratio | Electro Magnetic Applications Inc. | $39,715 |
| | | $671,224 |

EAT/M-024

# GEOTHERMAL EXPLORATION AND ASSESSMENT TECHNOLOGY PROGRAM

## OUTSIDE CONTRACTS: FY-1980

| | | |
|---|---|---|
| Investigation of Water-Rock Reaction at Cerro Prieto | Elders-UCR | $ 99,991 |
| Investigation of Water-Rock Reaction in Japan and Taiwan | Liou-Stanford | 96,717 |
| Evaluation of Na-K-Ca Geothermometer | Nur/Parks-Stanford | 98,815 |
| Microearthquake Survey and Analysis | Cramer/Stierman-CA.D MG | 100,000 |
| | TOTAL | $395,523 |

GEOTHERMAL EXPLORATION AND ASSESSMENT TECHNOLOGY PROGRAM

# ESL/UURI IN-HOUSE PROGRAM

## BASED ON

- Adaptation of mining techniques
- Development of new techniques
- Work on topics of specific expertise

GEOLOGICAL TECHNIQUE DEVELOPMENT

GEOCHEMICAL TECHNIQUE DEVELOPMENT

GEOPHYSICAL TECHNIQUE DEVELOPMENT

EXPLORATION STRATEGIES

# GEOPHYSICAL TECHNIQUE DEVELOPMENT

## COMPUTER ALGORITHMS

Mathematical development and computer implementation of 2D and 3D interpretation techniques for exploration, well siting & drilling

## TECHNIQUE EVALUATION

Improve and adopt field techniques to geothermal enviroment for exploration & well siting

## TECHNIQUES STUDIED

- Resistivity
- Induced polarization (IP)
- Magnetotellurics (MT)
- Audiomagnetotellurics (AMT)
- Electromagnetics (EM)
- Controlled source AMT (CSAMT)
- Self potential (SP)
- Shallow (3 meter) temperature measurements

# COMPUTER PROGRAMS AND MODEL CATALOGS

## OBJECTIVE

Make interpretation aids available to industry

## JUSTIFICATION

Better interpretation should lead to more geothermal discoveries

Most companies do not have resources to develop numerical solutions

## APPROACH

Publish documented computer programs

Publish catalogs of interpretation models

EAT/GP-010

# COMPUTER PROGRAMS PUBLISHED

| PROGRAM | NO. DISTRIBUTED |
|---|---|
| 2D RESISTIVITY | 160 |
| 2D RESISTIVITY INVERSION | 7 |
| 2D MAGNETOTELLURIC | 35 |
| 3D MAGNETOTELLURIC | 10 |
| SCHLUMBERGER INVERSION | 31 |
| $2\frac{1}{2}$ D GRAVITY | 20 |
| $2\frac{1}{2}$ D MAGNETICS | 7 |
| 3D GRAVITY & MAGNETICS | 19 |
| WELL LOG ANALYSIS | 17 |
| GRAVITY TERRAIN CORRECTION | 6 |

EAT/GP-011

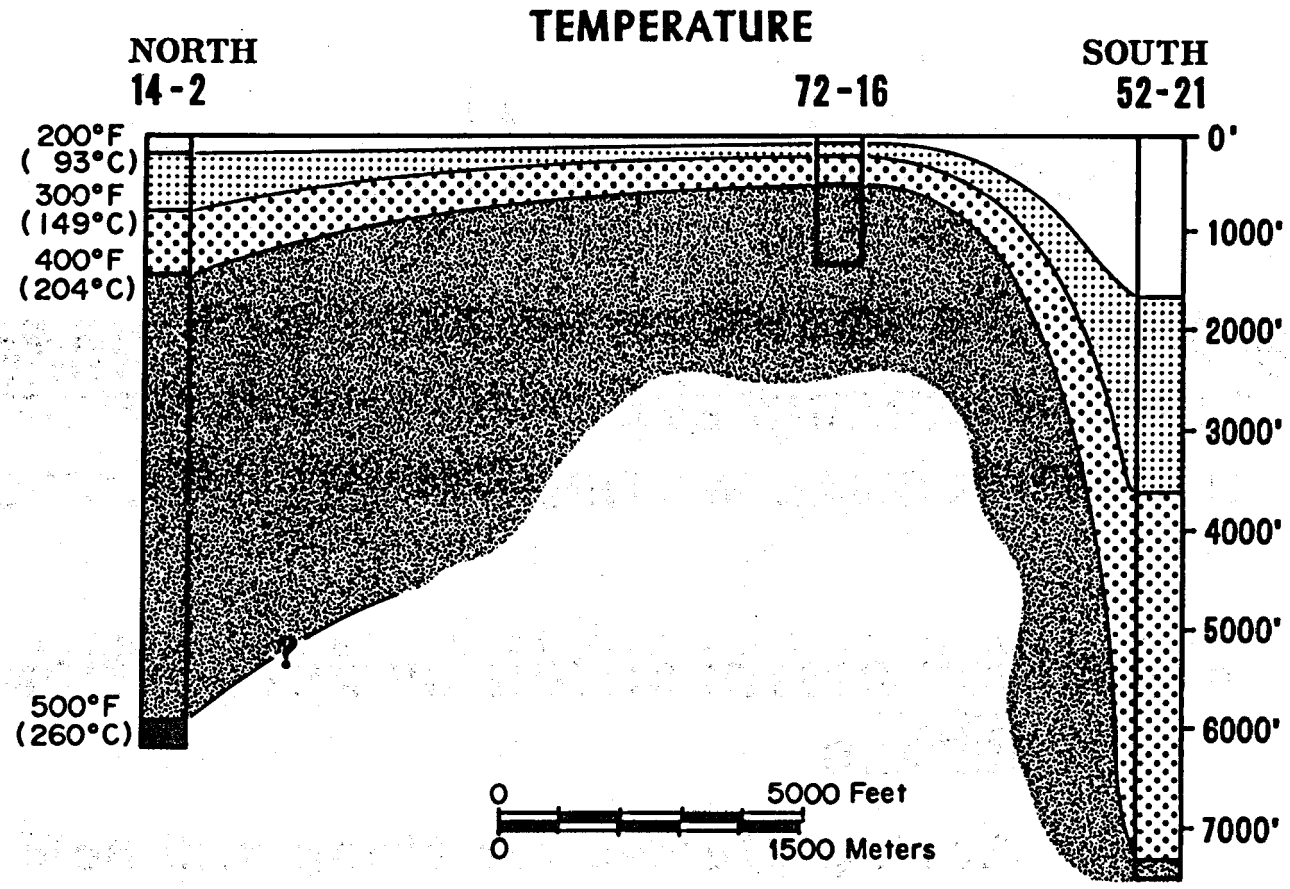
## GEOCHEMICAL TECHNIQUE DEVELOPMENT

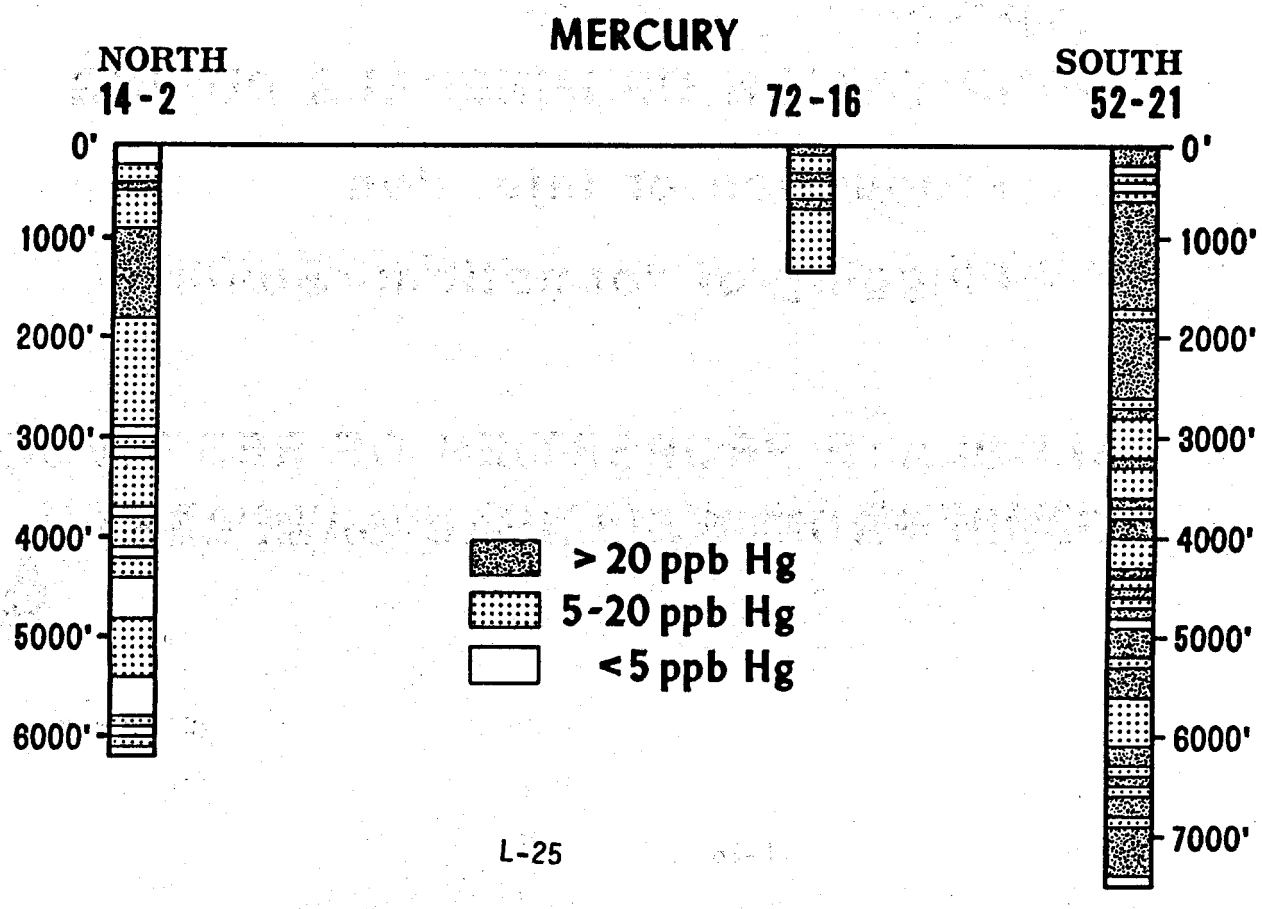
# MAJOR ACCOMPLISHMENTS

1. DEVELOPMENT OF SUBSURFACE TRACE ELEMENT ZONING MODELS FOR GEOTHERMAL EXPLORATION
2. DEVELOPMENT OF SOIL TRACE ELEMENT ZONING MODELS FOR GEOTHERMAL EXPLORATION
3. PREDICTION OF SUBSURFACE TEMPERATURES, FLUID COMPOSITIONS, AND ALTERATION MINERALOGY OF HIGH TEMPERATURE THERMAL SYSTEMS
4. REFINEMENT OF MATHEMATICAL MODELS FOR ESTIMATING WATER/ROCK RATIOS AND FLUID RESIDENCE TIMES
5. PREPARATION OF 22 REPORTS AND ABSTRACTS

# SUBSURFACE TRACE ELEMENT STUDIES

- DEFINE SIZE AND SHAPE OF GEOTHERMAL SYSTEM
- DISTINGUISH PERMEABLE FROM IMPERMEABLE ZONES
- LOCATE AREAS OF HIGH PERMEABILITY
- DETERMINE SUBSURFACE TEMPERATURES


TEMPERATURE
NORTH
14-2
72-16
SOUTH
52-21
200°F
( 93°C)
300°F
(149°C)
400°F
(204°C)
500°F
(260°C)
?
0'
1000'
2000'
3000'
4000'
5000'
6000'
7000'
0
5000 Feet
0
1500 Meters


MERCURY
NORTH
14-2
72-16
SOUTH
52-21
0'
1000'
2000'
3000'
4000'
5000'
6000'
7000'
>20 ppb Hg
5-20 ppb Hg
<5 ppb Hg

# GEOCHEMICAL MODELING

☆EXTENSIVE SET OF OPERATING PROGRAMS FOR PREDICTING AND EVALUATING EFFECTS OF HYDROTHERMAL WATER/ROCK INTERACTION

- PREDICT DISTRIBUTION OF ALTERATION MINERALS
  - Zoning Studies for siting drill holes
  - Recognition of fractures in cuttings
- PRECIPITATION OF MINERALS DURING
  - Production or Injection
  - Plugging of formation; Scaling
- CALCULATE PROPERTIES OF RESERVOIR FLUID FROM WELLHEAD SAMPLES

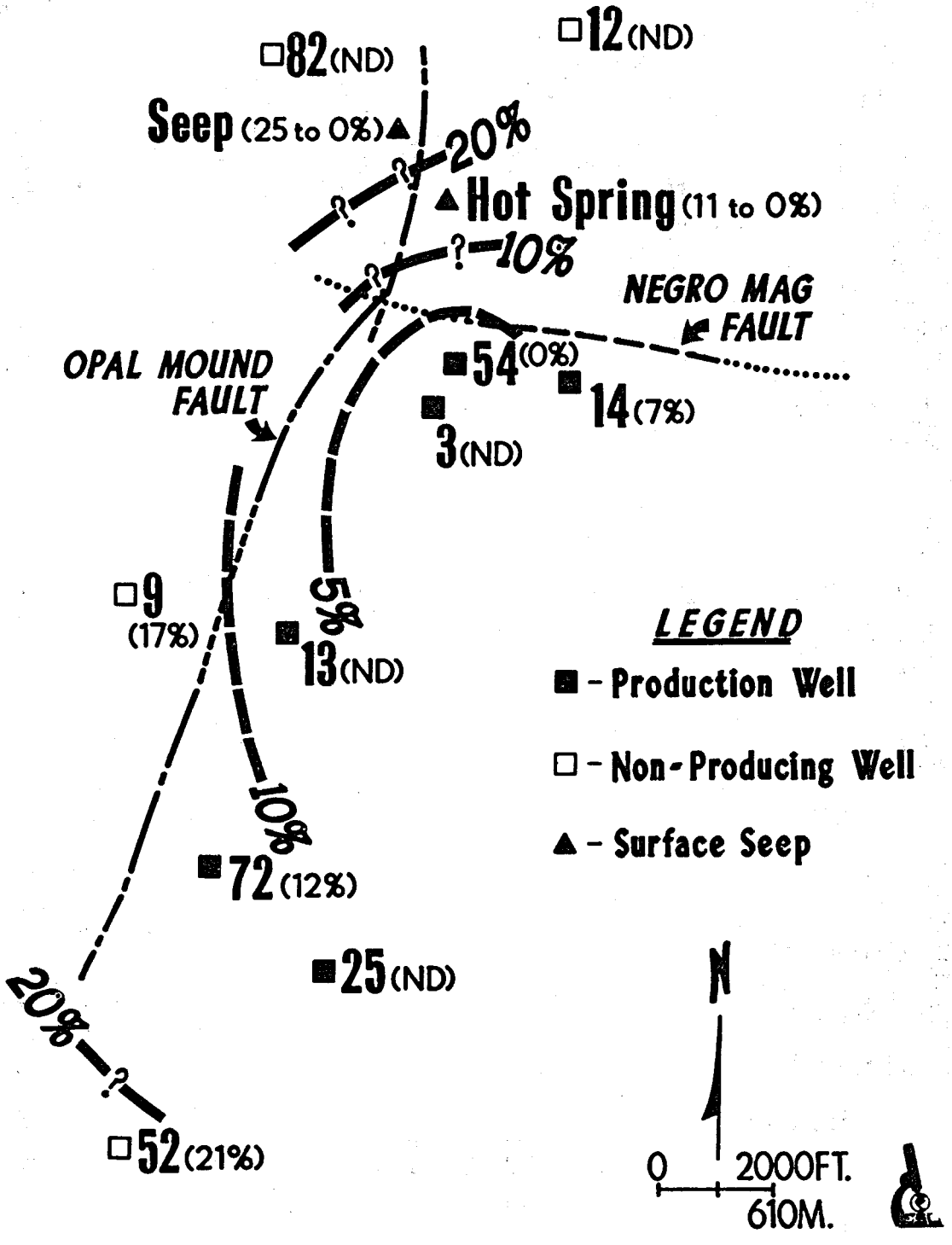
EAT/Gc-63

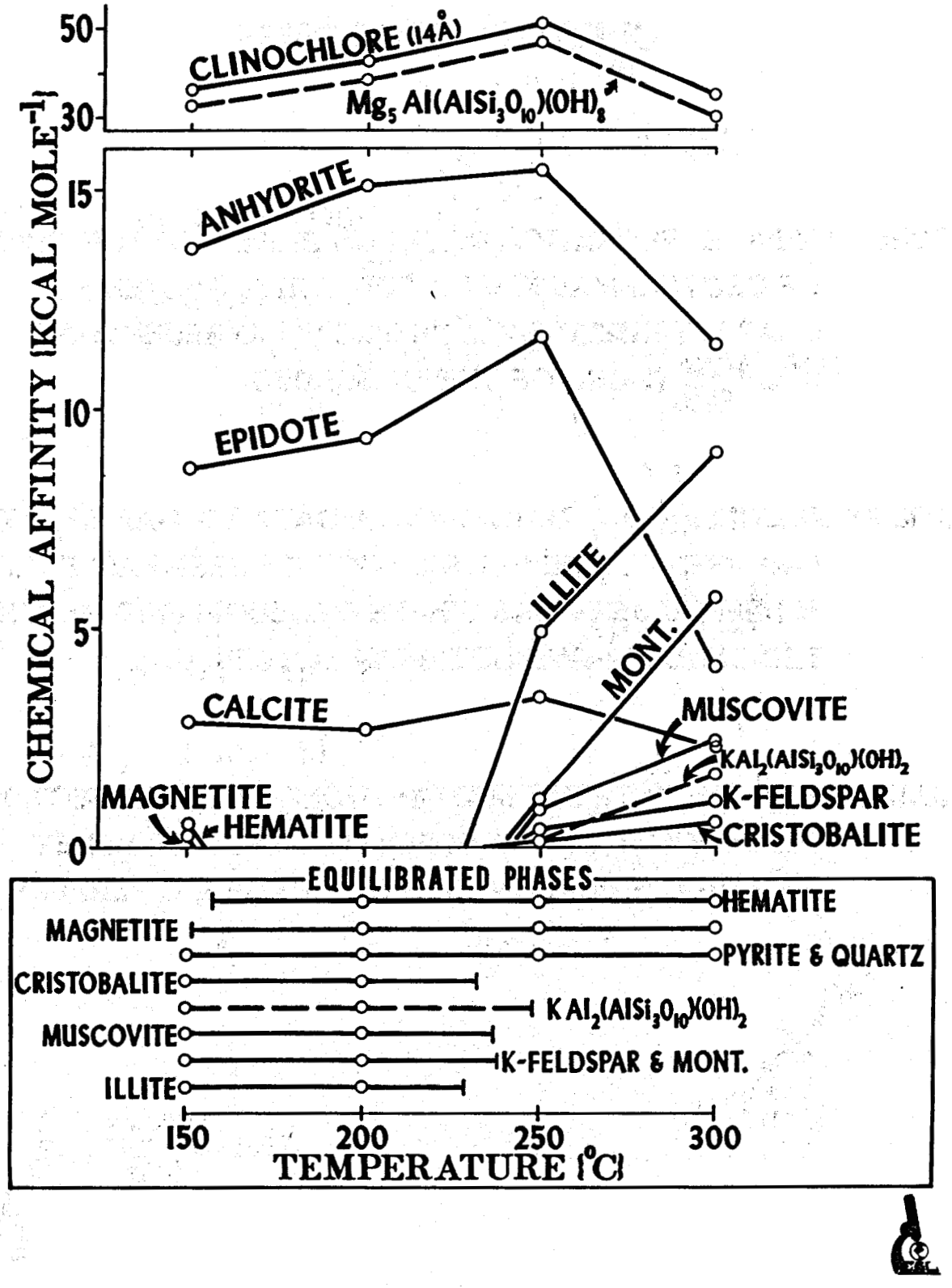
# Roosevelt Hot Springs Fluid Analyses

## WELL 14-2

| | Brine Sampled at the Surface (ppm) | Calculated Deep Reservoir Fluid (ppm) |
|---|---|---|
| Na | 2190 | 1796 |
| K | 401 | 329 |
| Ca | 8 | 12 |
| Si | 341 | 280 |
| Cl | 3650 | 2993 |
| C | 206 | 1793 |
| S | 69 | 138 |
| T.D.S. | 6680 | 9707 |
| pH | 6.1 | 5.8 |
| Na-K-Ca (°C) | 289 | 277 |
| Quartz cond. (°C) | 289 | 269 |

EAT/Gc064


□82(ND)
□12(ND)
Seep (25 to 0%)▲
20%
▲Hot Spring (11 to 0%)
10%
NEGRO MAG FAULT
OPAL MOUND FAULT
■54(0%)
■14(7%)
■3(ND)
□9 (17%)
5%
■13(ND)
10%
■72(12%)
■25(ND)
20%
□52(21%)
LEGEND
■ - Production Well
□ - Non-Producing Well
▲ - Surface Seep
N
0
2000FT.
610M.


CHEMICAL AFFINITY (KCAL MOLE$^{-1}$)
50
30
15
10
5
0
CLINOCHLORE (14Å)
$Mg_5Al(AlSi_3O_{10})(OH)_8$
ANHYDRITE
EPIDOTE
ILLITE
MONT.
CALCITE
MUSCOVITE
$KAl_2(AlSi_3O_{10})(OH)_2$
K-FELDSPAR
CRISTOBALITE
MAGNETITE
HEMATITE
EQUILIBRATED PHASES
HEMATITE
MAGNETITE
PYRITE & QUARTZ
CRISTOBALITE
$KAl_2(AlSi_3O_{10})(OH)_2$
MUSCOVITE
K-FELDSPAR & MONT.
ILLITE
150
200
250
300
TEMPERATURE (°C)

## GEOCHEMICAL TECHNIQUE DEVELOPMENT

# CURRENT PROGRAMS

- DEVELOP NEW EXPLORATION METHODS BASED ON THE CHEMISTRY OF GEOTHERMAL FLUIDS FOR USE IN SYSTEMS CHARACTERIZED BY MULTIPLE FLUID RESERVOIRS SUCH AS THOSE OF THE CASCADES.

- UTILIZE MULTIELEMENT GEOCHEMICAL DATA TO MAP STRATIGRAPHY AND PREDICT THE DISTRIBUTION OF PERMEABLE ZONES IN DEEP RESERVOIRS WHERE GEOLOGIC AND GEOPHYSICAL TECHNIQUES HAVE NOT BEEN SUCCESSFUL.

- QUANTIFY TRACE ELEMENT DISTRIBUTIONS WITH RESPECT TO TEMPERATURE, FLUID CHEMISTRY , AND COMPLEX GEOLOGIC ENVIRONMENTS (CASCADES, IMPERIAL VALLEY ) .