From BPA/WMT Meyer 7/3/8

1983 Northwest Conservation and Electric Power Plan Volume I

Adopted Pursuant to the Pacific Northwest Electric Power Planning and Conservation Act of 1980 (P.L. 96-501)

GL01626

April 27, 1983

Chapter 8

Geothermal

Geothermal energy has the potential for a large contribution to the region's electric energy supply. However, opinions are divided as to how much electric energy and at what price. A Council study estimated more than 2,000 average megawatts of electric generation were available from high-temperature (greater than 150 degrees centigrade) resources at costs ranging from 3.2 to 8.8 cents per kilowatt-hour. In addition, intermediate-temperature (90 to 150 degrees centigrade) hydrothermal resources could provide direct heating for groups of houses and businesses, replacing 716 average megawatts of electricity at costs ranging from 3.0 to 6.5 cents per kilowatt-hour.

These estimates represent only part of the geothermal potential in the region. The Council has not examined geothermal resources at temperatures below 90 degrees centigrade for non-electric uses or temperatures between 90 and 150 degrees centigrade for electric generation. Some communities in the region, including Boise, Idaho, have developed low-temperature resources for space heating, and estimates show that other communities could exploit geothermal resources to provide cost-effective space heating. Efforts are underway in the region and in California to generate electricity from geothermal fluid in the 100 to 115 degrees Centigrade range using wellhead generators. The Council will monitor progress in these areas.

The geothermal resource is large, and effective technology to develop these sites exists. However, more precise information would be needed on temperature and chemical makeup of the geothermal fluid, size of promising geothermal reservoirs, and all related costs before the Council could forecast geothermal energy to be a cost-effective resource in the plan. Considerable information about the region's geothermal resource has already been documented by the U.S. Geological Survey in their Geological Survey Circular 790, published in 1979. Since that time, the U.S. Department of Energy and the four states of the region have extended that information. The Council does not see additional expensive resource exploration as the responsibility of Bonneville, and expects that traditional funding sources for those activities will continue.

The Council has identified actions to encourage cost-effective geothermal resource development. The Council expects to include power from geothermal energy as a firm resource in subsequent revisions to the plan. Detailed actions to achieve this goal are described in the two-year action plan, chapter 10.

Chapter 10

17. Geothermal

The Council has concluded that a large geothermal potential exists in the region for both electric generation and direct applications that decrease the need for electricity. (Direct applications of geothermal and other renewable resources are considered in chapter 7, Conservation.) However, the precise size, characteristics, and technical potential of the geothermal resouces has not been determined. The objective of this program is to encourage confirmation of the region's geothermal resource for electric generation so it can be developed quickly when the need exists. The following actions are expected to provide a base for including geothermal resources in future plans.

Bonneville Action

Bonneville shall:

17.1 Develop and implement a geothermal demonstration program that guarantees the purchase of electricity from the first 10 average megawatts generated at the most promising environmentally acceptable geothermal site available in the region. The site should be estimated to be able to produce at a capacity of 100 megawatts or more over a 30-year period. There should be a clear agreement that if the field is developed it would be available to the region at competitive prices. The fixed purchase price should be tied to the cost to Bonneville of the energy from a new coal plant. Recognizing the demonstration nature of this venture, Bonneville should be prepared to pay a price up to 50 percent higher than the cost of energy from a new coal plant at the time of acquisition. If this program proves workable, and as need dictates, the Council will consider expanding this program to other promising sites in the region.

Department of Energy
Bonneville Power Administration
P.O. Box 3621
Portland, Oregon 97208

OFFICE OF THE ADMINISTRATOR

In reply refer to: PRTA

October 5, 1984

Dr. Michael Wright
UURI, Earth Science Lab.
391 Chipeta Way, Suite C
Salt Lake City, Utah 84108

Dear Mike:

As discussions and insights resulting from your presentation last Tuesday continue, I wish to pause and express our appreciation for your help. As the Northwest Regional Power Council and Bonneville Power Administration try to select the most appropriate and effective means of addressing geothermal resources of the region, improved understanding such as you provided is our most valuable tool. Opportunities to benefit from experience gained elsewhere can only be realized through interpretation by someone willing and able to share. Both the timing and nature of your input are precisely what we need.

Most current discussions are more administrative than technical in nature. Even so, procedures and relationships among exploratory techniques frequently surface in questions. As specific issues or concepts are raised, I suspect we will take you up on your offer of future assistance.

Again, our most sincere "Thanks" are offered to both you and Dr. Molloy for the crash course on exploration concepts in general and requirements of the Cascades in particular.

Sincerely,

John D. Geyer
Energy Resource Specialist

cc:
Dr. M. W. Molloy
DOE, San
1333 Broadway
Oakland CA 94612

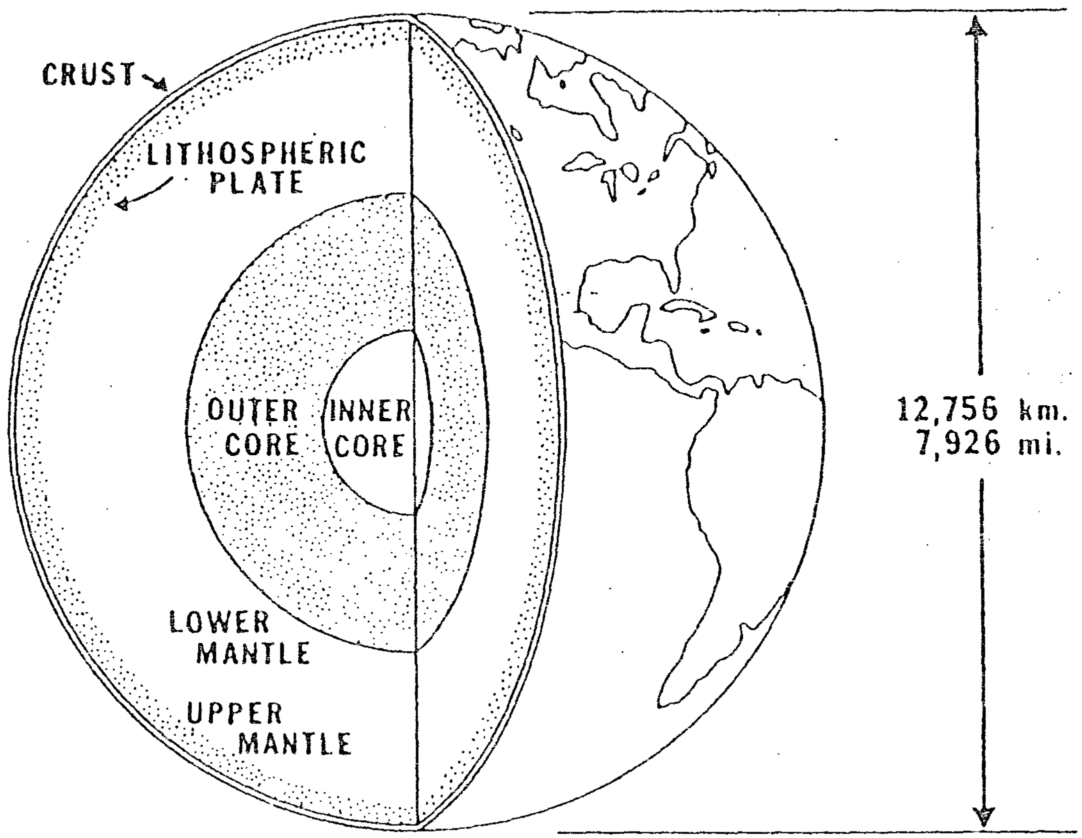
STATE COUPLED PROGRAM

DIRECT VS INDIRECT DETECTION

DIRECT METHOD - TEMPERATURE MEASUREMENT
SPRINGS AND WELLS

INDIRECT METHODS
- HEAT FLOW STUDIES
- GRADIENT EXTRAPOLATION
- CHEMICAL GEOTHERMOMETRY
- GEOLOGIC MAPPING
- GEOPHYSICAL SURVEYS
- GEOCHEMICAL SURVEYS
- HYDROLOGIC STUDIES

SC-013



UURI

PHILLIP MICHAEL WRIGHT
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RESEARCH PARK
391 CHIPETA WAY
SUITE C
SALT LAKE CITY, UTAH 84108

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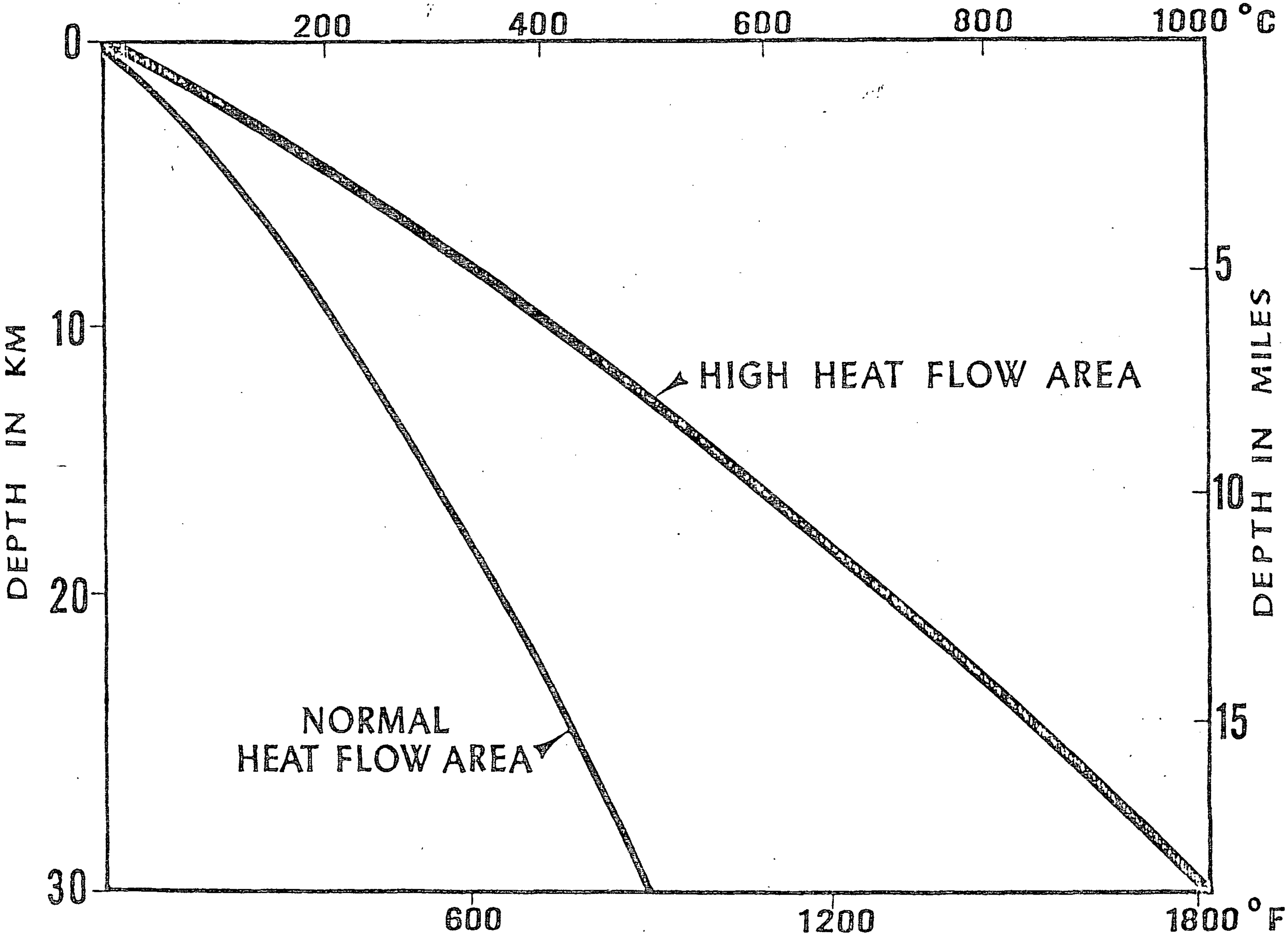
GG-006

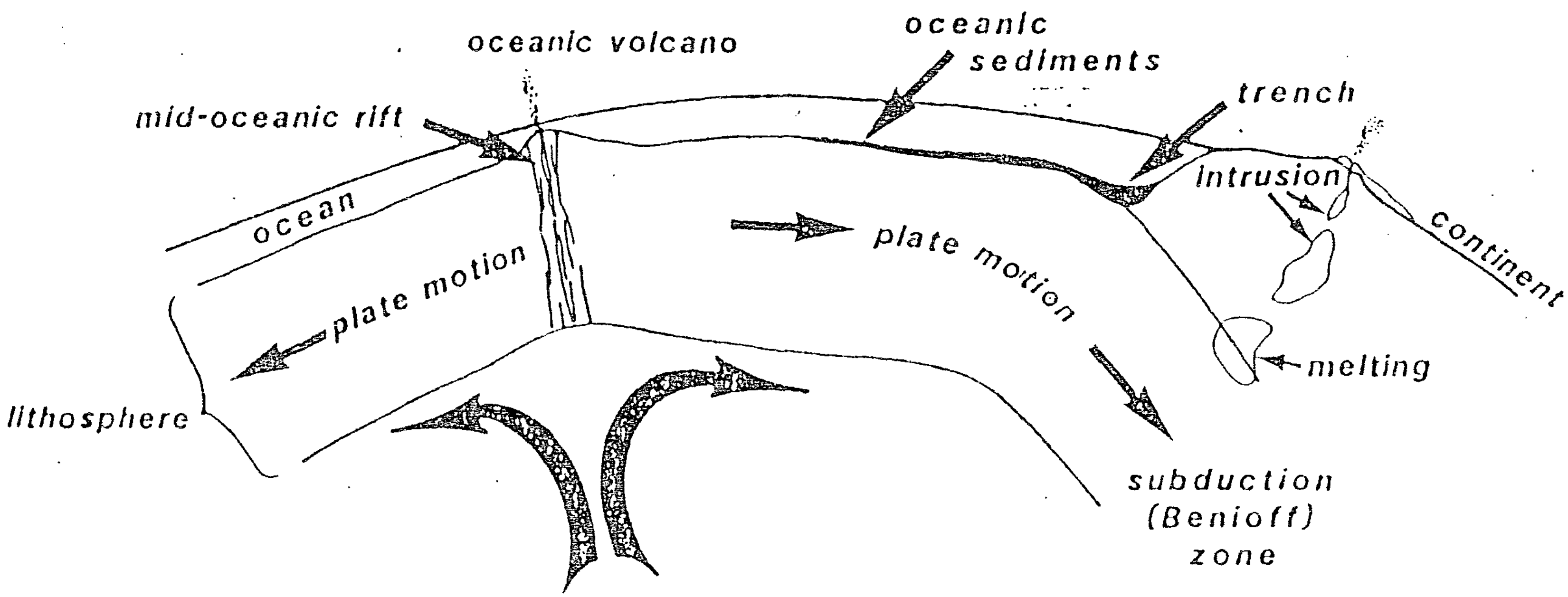
TEMPERATURE VS DEPTH IN EARTH



SC/MW-004

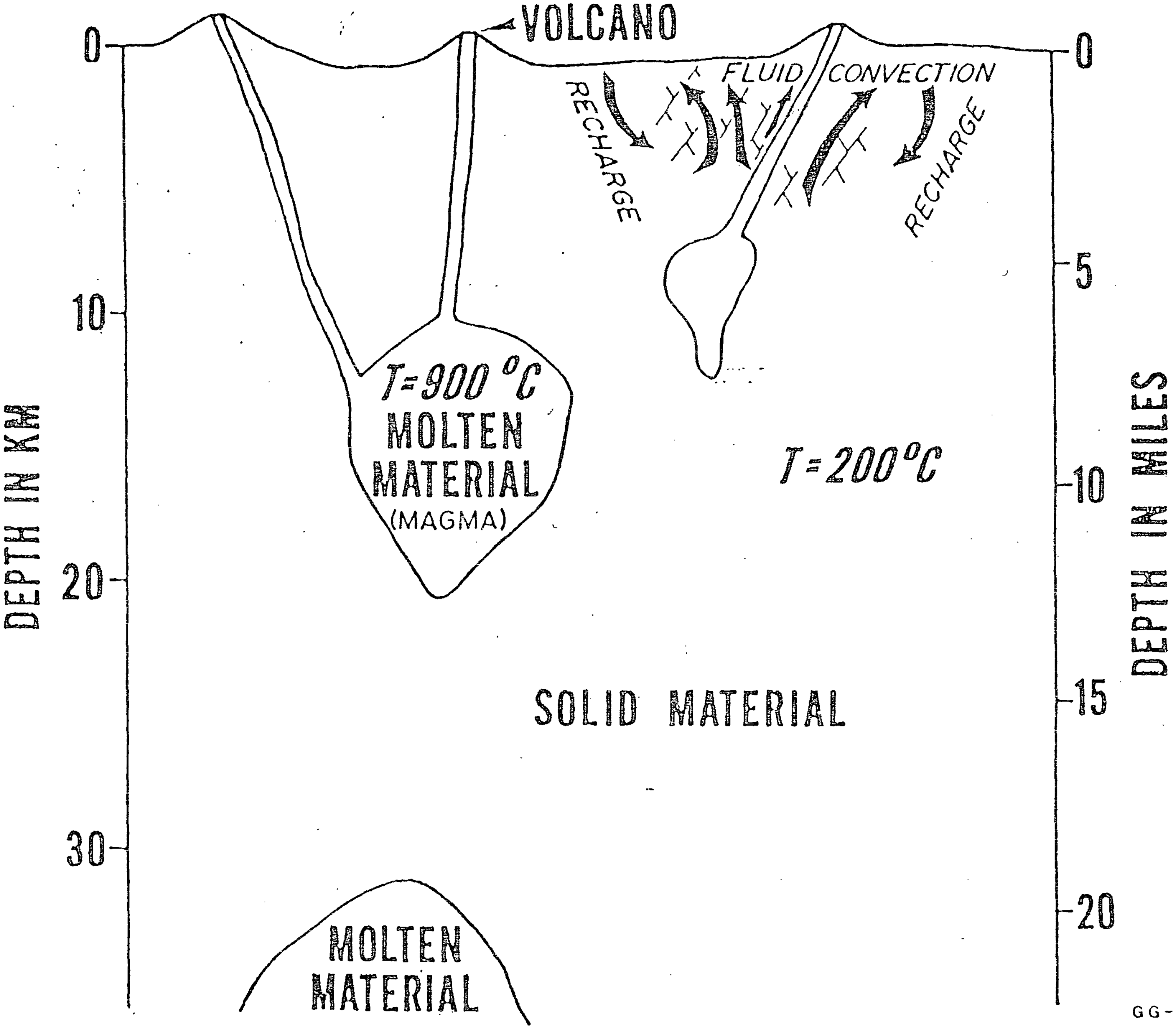
CONCEPT OF PLATE TECTONICS

(not to scale)



GG-006a
evised 1/81

CRUSTAL INTRUSION

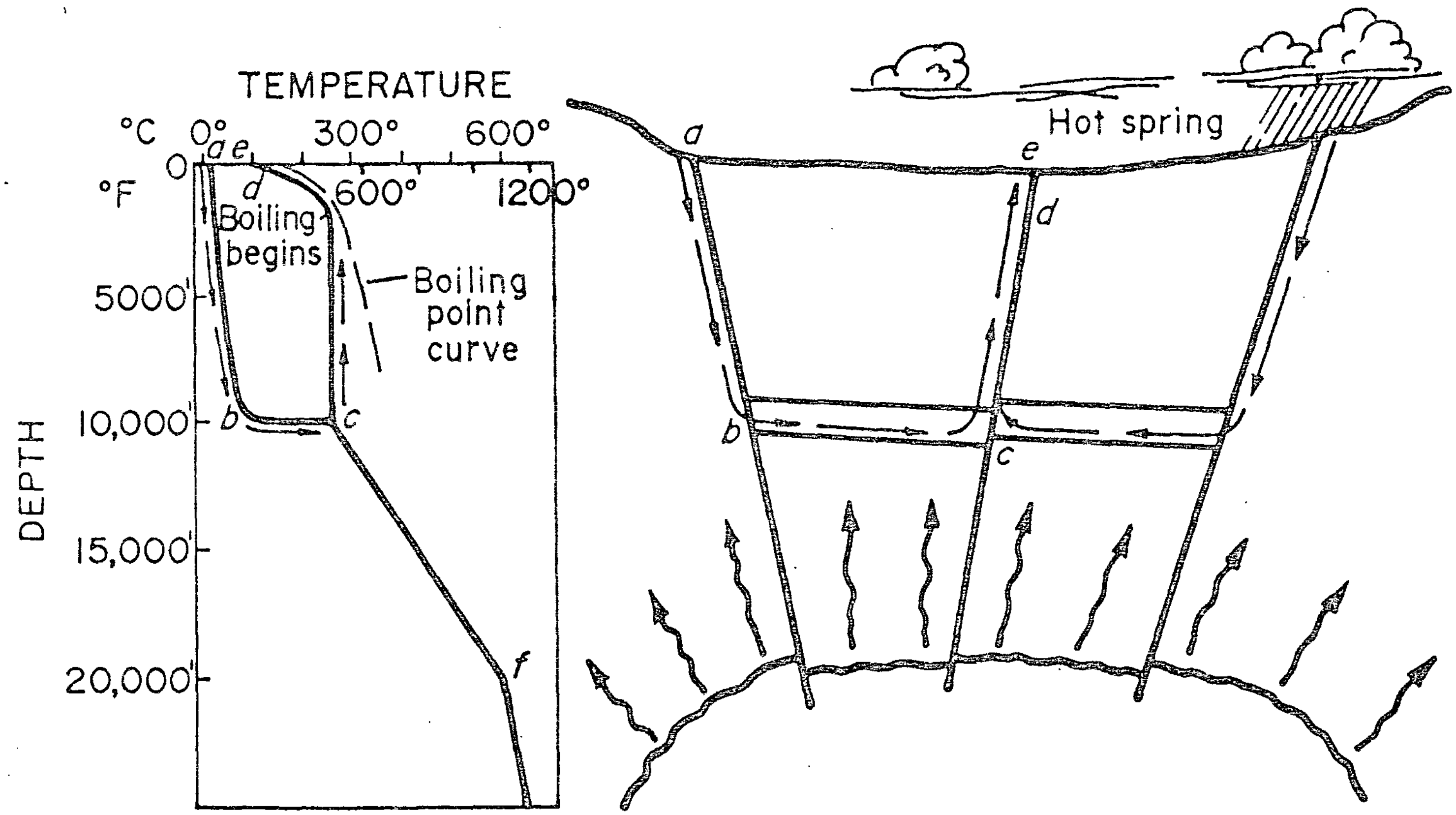


GG-082

Characteristics of Geothermal Resources

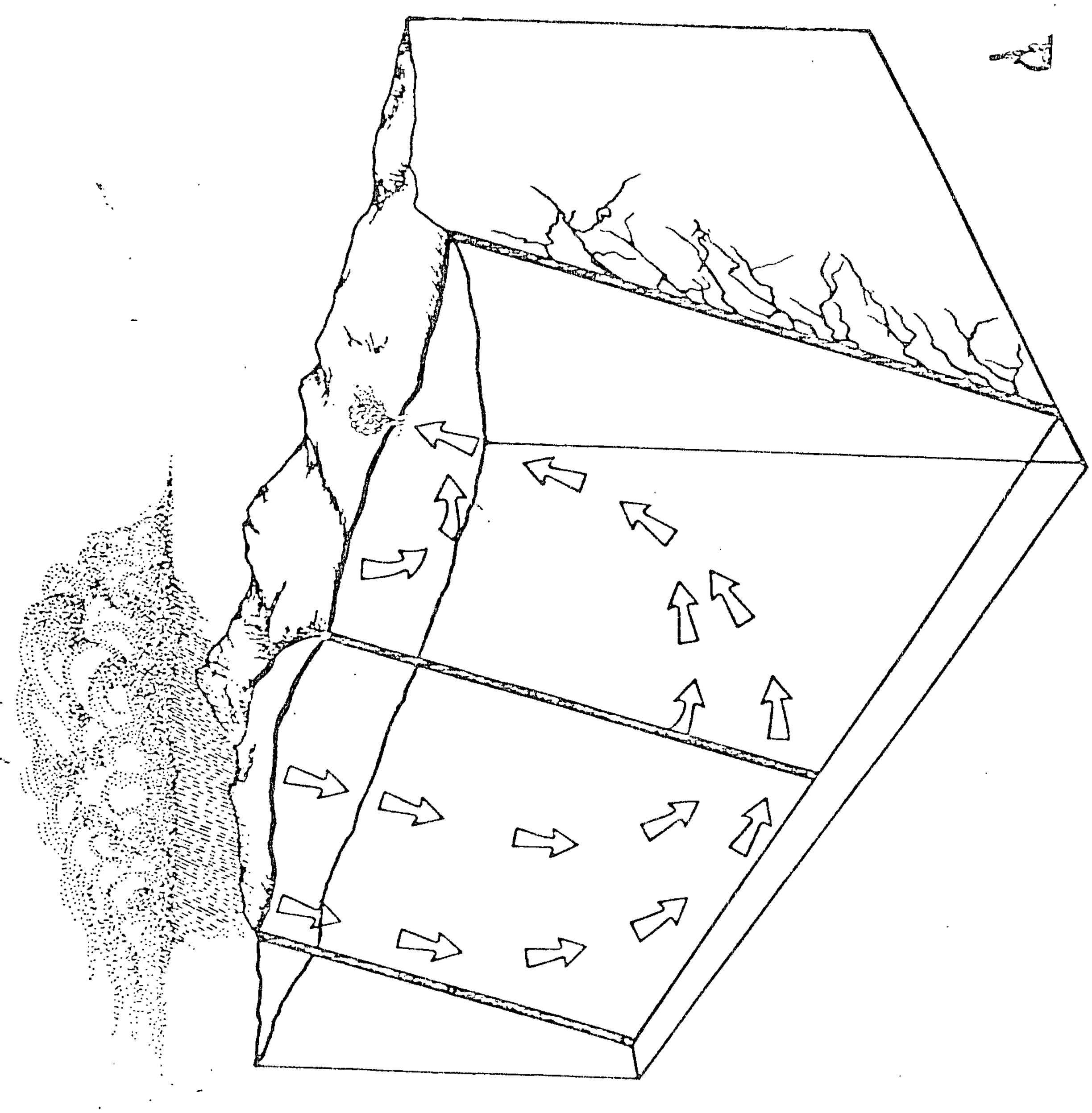
- Source of heat
  - — Volcanic activity
  - — Igneous intrusion
- Water to transfer heat
- Permeable rocks

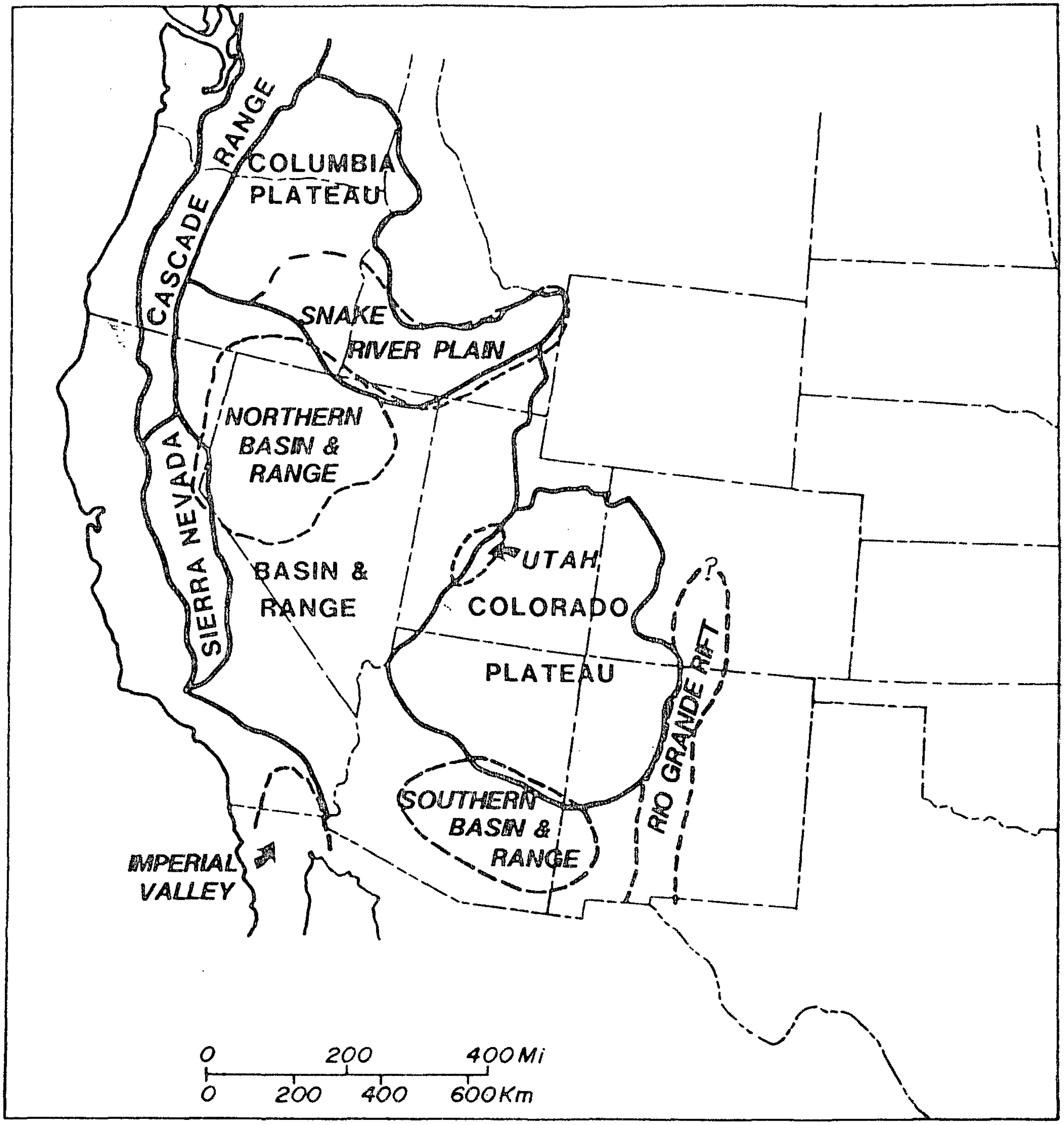
S2 0369



TEMPERATURE
°C
0°
300°
600°
°F
0
600°
1200°
a
e
d
Boiling begins
Boiling point curve
DEPTH
5000'
10,000'
15,000'
20,000'
b
c
f
a
e
d
Hot spring
b
c

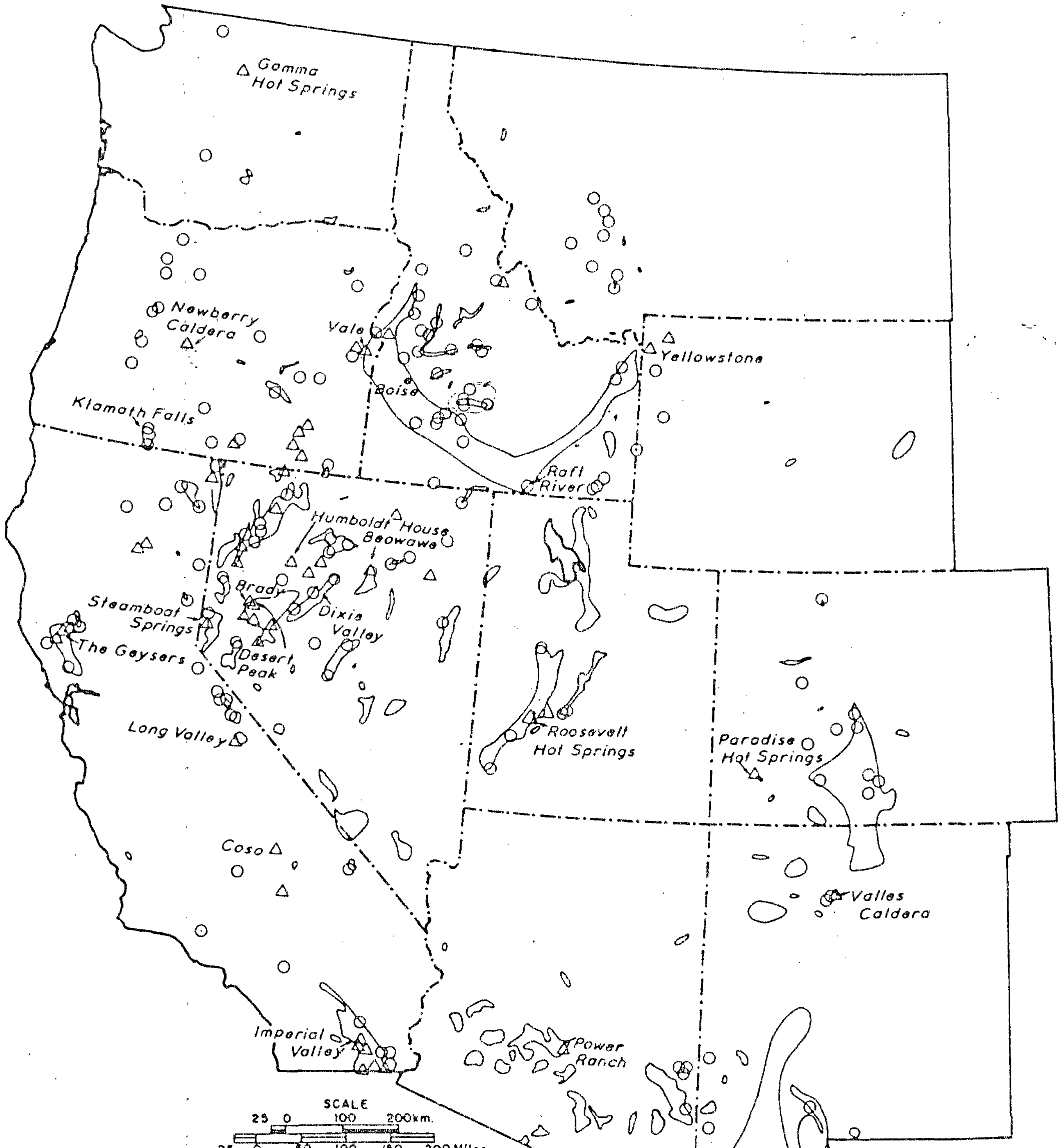
GG-014





GEOTHERMAL RESOURCE REGIONS

HYDROTHERMAL RESOURCES IN THE WESTERN UNITED STATES



EXPLANATION

HYDROTHERMAL CONVECTION SYSTEMS

△ >150°C

○ 90°–150°C

LOW TEMPERATURE GEOTHERMAL WATER

GEOLOGIC ENVIRONMENTS

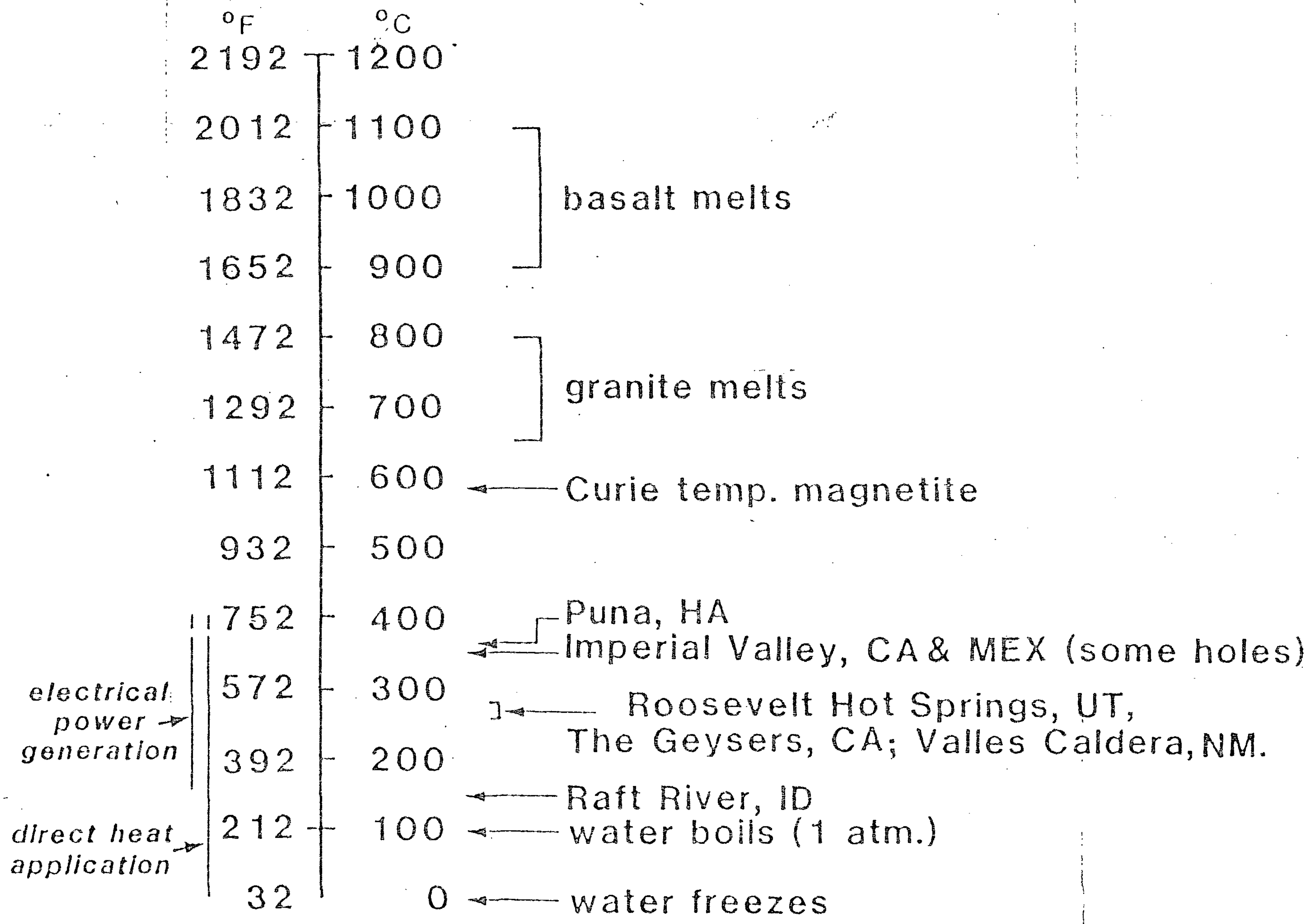
HIGH-TEMP. RESOURCES
($\geq 150^\circ C$)

1. Basin and Range
2. Imperial Valley
3. Cascades
4. Snake River Plain
5. Rio Grande Rift

LOW and MOD. TEMP. RESOURCES
($< 150^\circ C$)

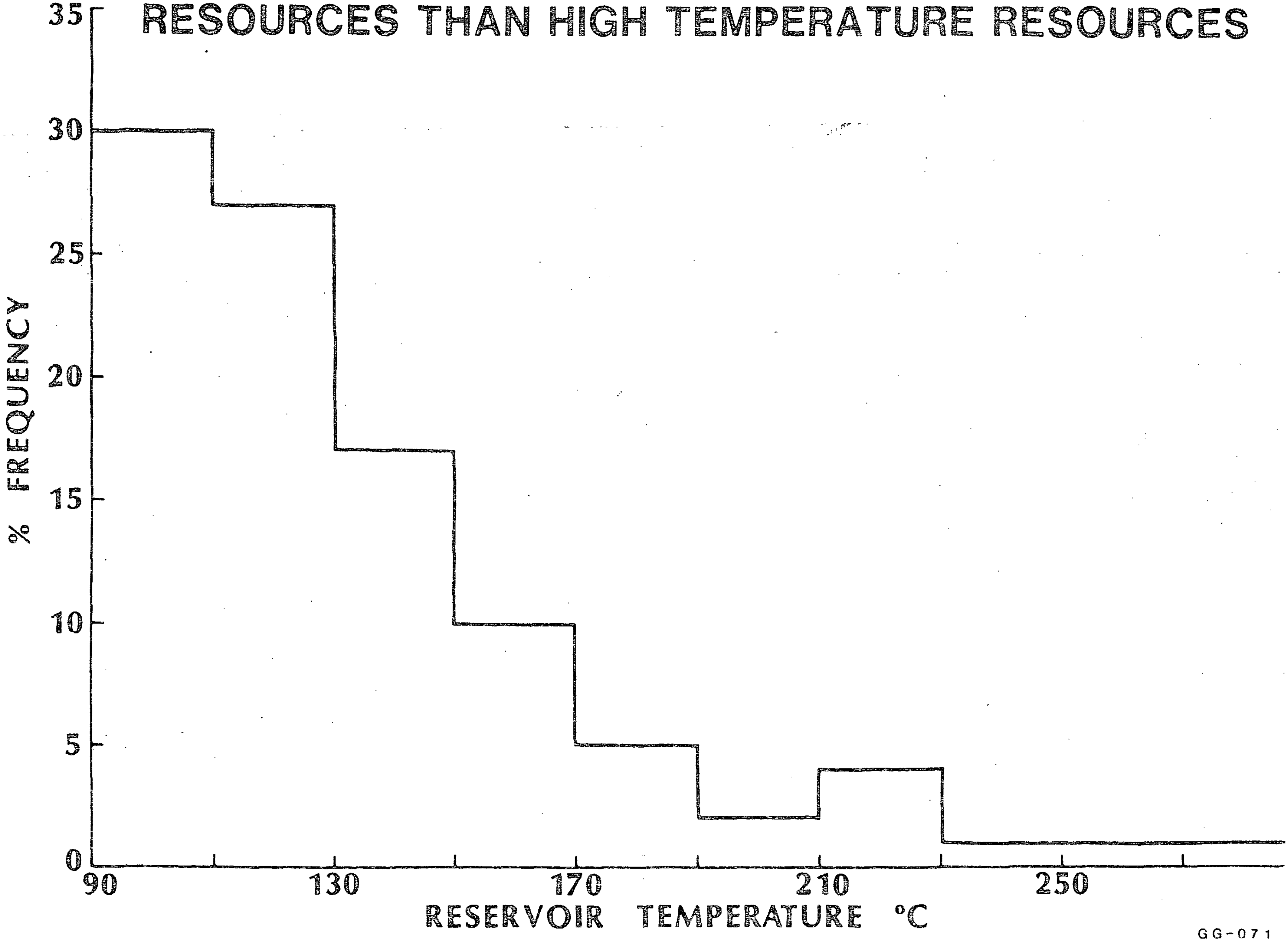
1. Basin and Range
2. Imperial Valley
3. Cascades
4. Snake River Plain
5. Rio Grande Rift
6. Madison
7. Balcones Fault Zone
8. Atlantic Coastal Plain
9. Eastern Aquifers

GEOTHERMAL TEMPERATURES



GG-026a
revised 1/81

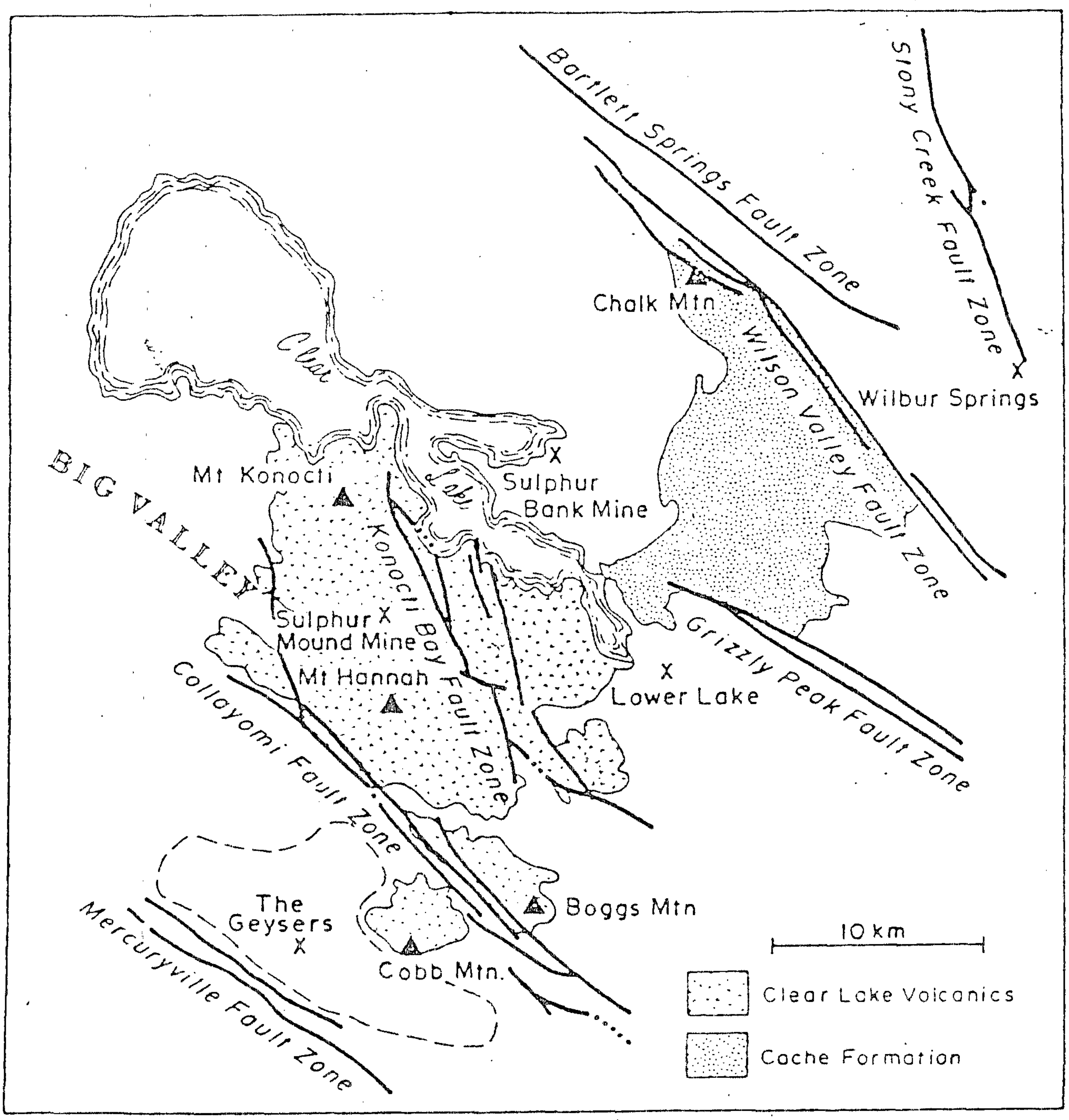
THERE ARE MANY MORE LOW TEMPERATURE RESOURCES THAN HIGH TEMPERATURE RESOURCES



GEOTHERMAL RESOURCES

Resource Type	Temp.
1. Hydrothermal (water or steam)	
a) Vapor dominated	≈ 240°C (464° F)
b) Hot-water dominated	
i) High temp	150°C to 300°C
ii) Intermed. temp	90°C to 150°C
iii) Low temp	<90°C
2. Hot igneous rock	
a) part still molten	>650°C
b) not molten (hot dry rock)	90°C to 650°C
3. Conduction-dominated	
a) radiogenic (radioactive decay)	30°C to ≈ 150 °C
b) geopressured (hot fluid, high pressure)	150°C to ≈ 200 °C

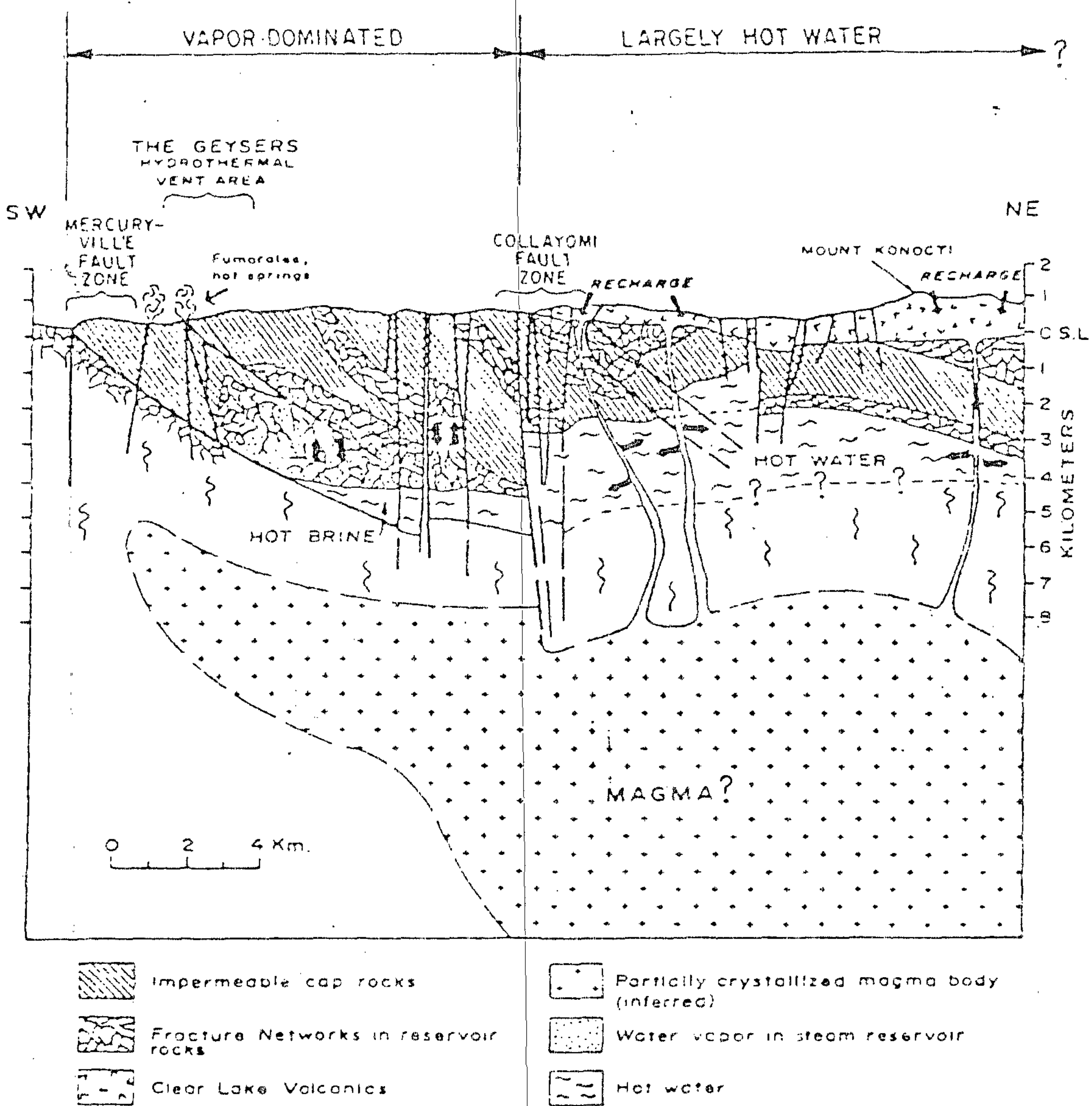
GG-030



MAJOR STRUCTURES in THE GEYSERS-CLEAR LAKE AREA

(After Goff, 1980)

Ca/Ge-002



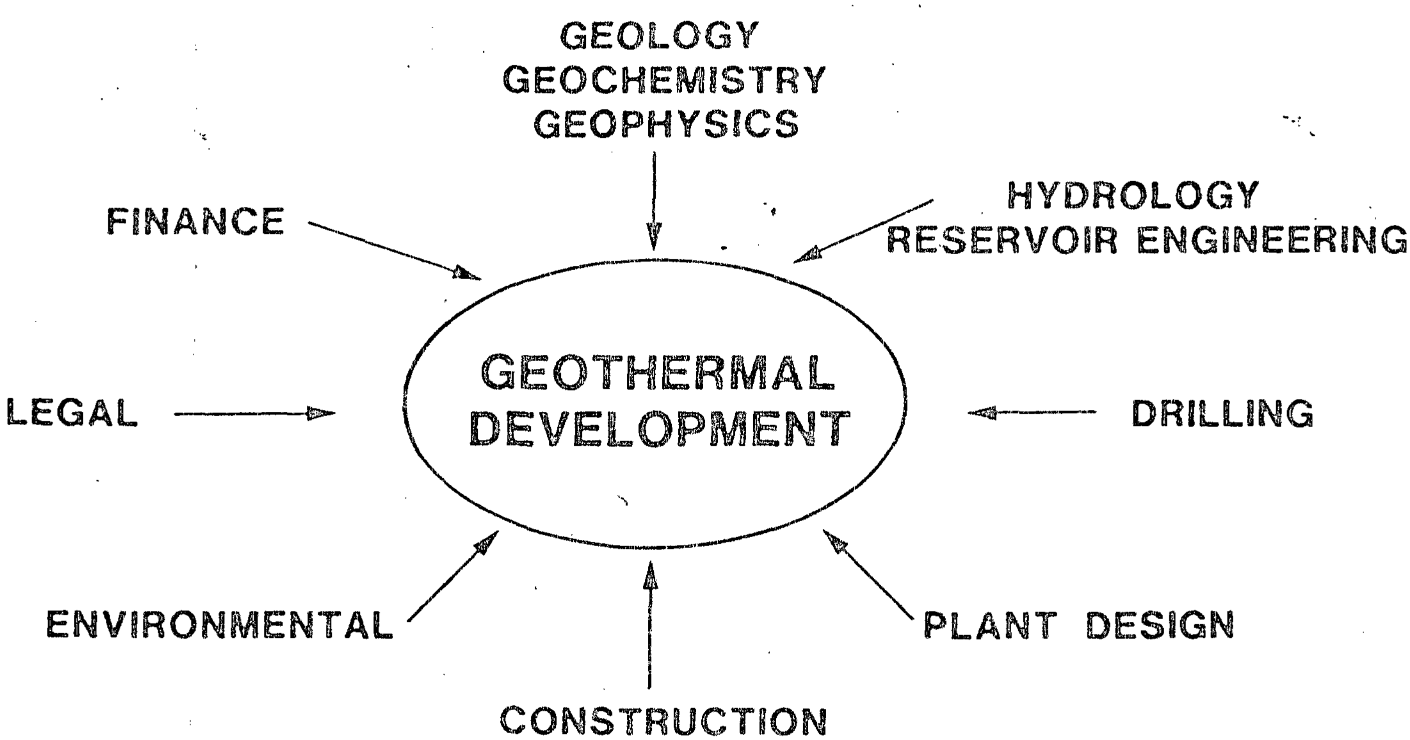
CRUSTAL MODEL FOR THE GEYSERS - CLEAR LAKE AREA, CA.

(after McLaughlin, 1977)

Ca/Ge-001

GEOTHERMAL DEVELOPMENT

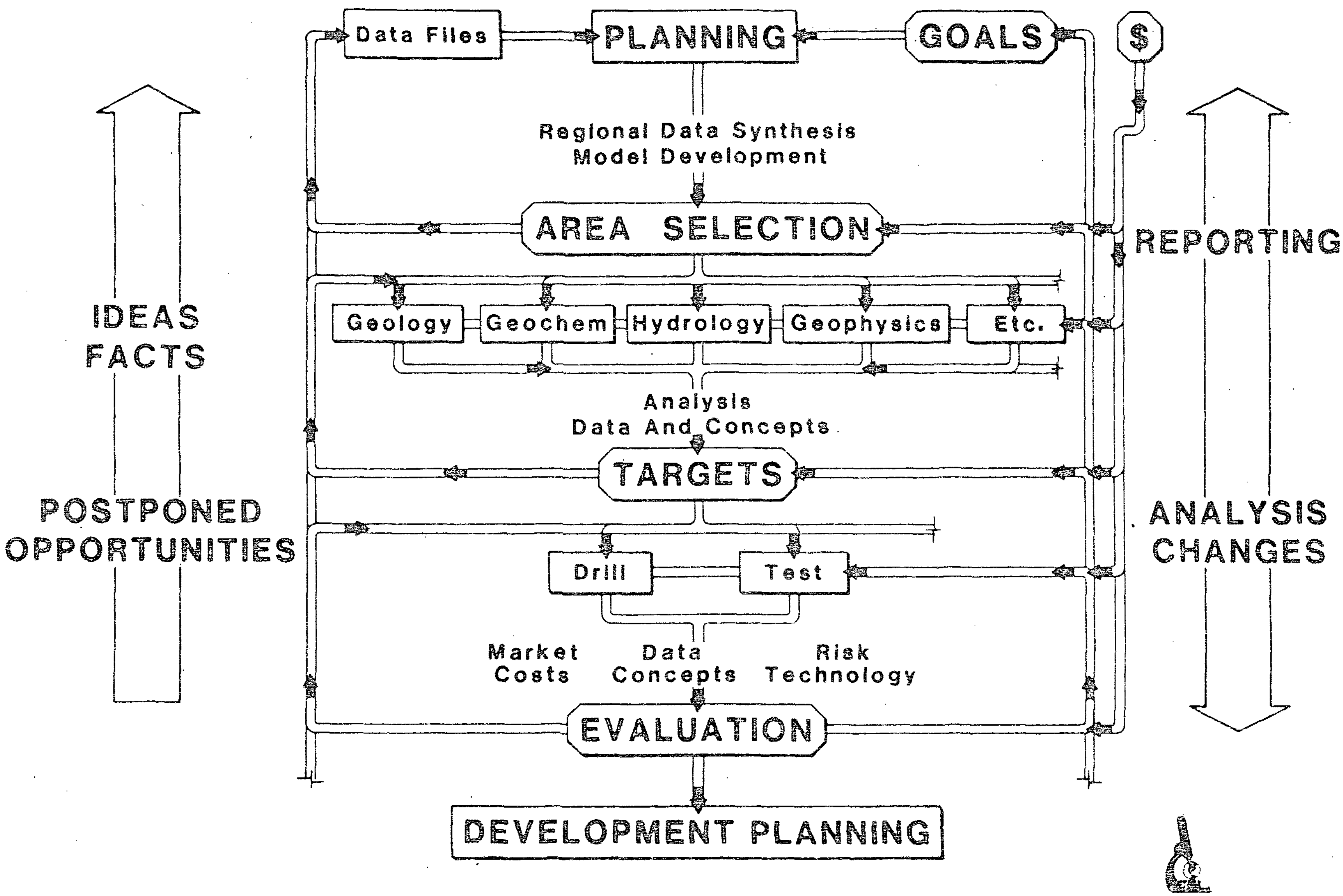
AN INTERDISCIPLINARY ENDEAVOR



THE DEVELOPMENT TEAM MUST WORK CLOSELY TOGETHER

FOR THE PROJECT TO SUCCEED

EXPLORATION



SC/MW-022

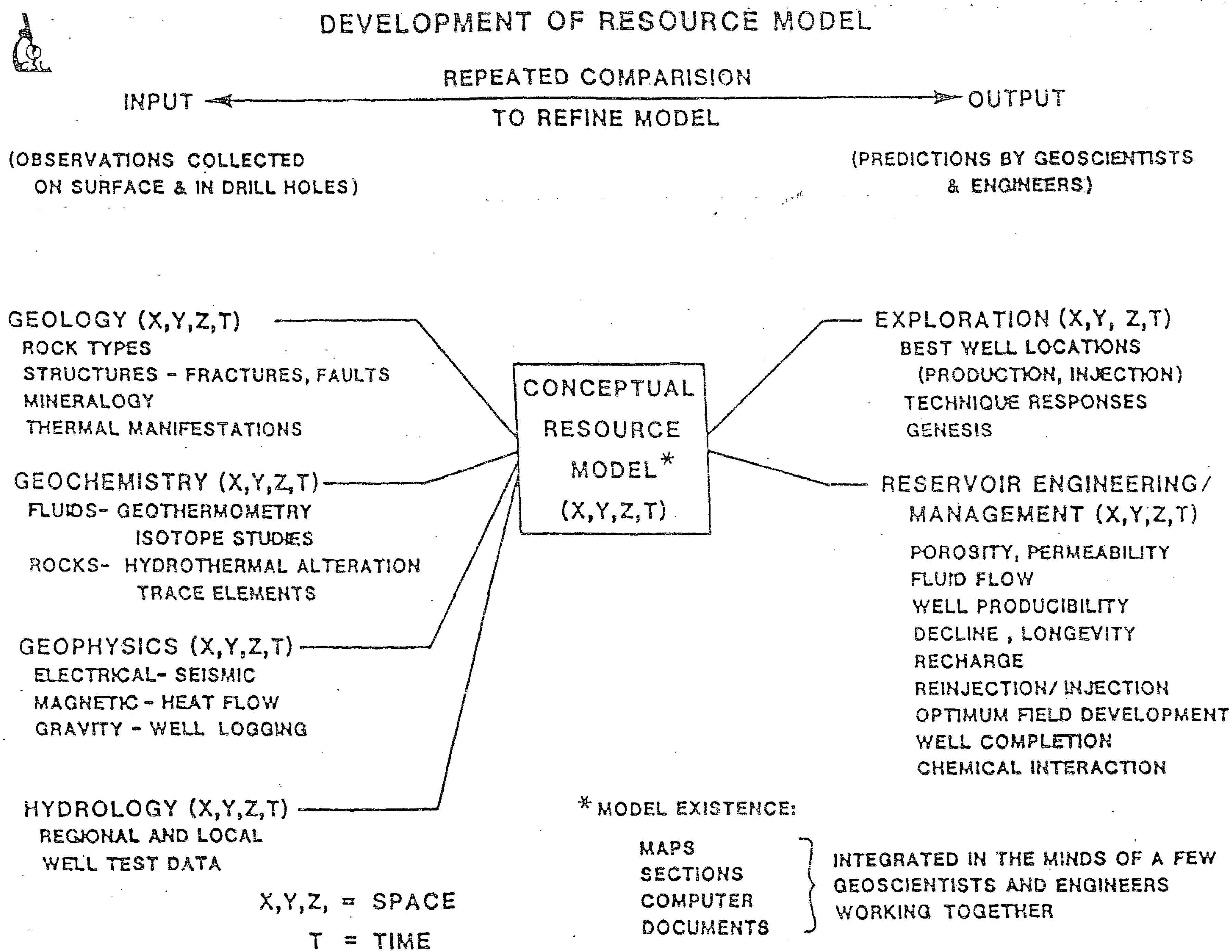

DEVELOPMENT OF RESOURCE MODEL
REPEATED COMPARISION
TO REFINE MODEL
INPUT
OUTPUT
(OBSERVATIONS COLLECTED ON SURFACE & IN DRILL HOLES)
(PREDICTIONS BY GEOSCIENTISTS & ENGINEERS)
GEOLOGY (X,Y,Z,T)
ROCK TYPES
STRUCTURES - FRACTURES, FAULTS
MINERALOGY
THERMAL MANIFESTATIONS
GEOCHEMISTRY (X,Y,Z,T)
FLUIDS- GEOTHERMOMETRY
ISOTOPE STUDIES
ROCKS- HYDROTHERMAL ALTERATION
TRACE ELEMENTS
GEOPHYSICS (X,Y,Z,T)
ELECTRICAL- SEISMIC
MAGNETIC - HEAT FLOW
GRAVITY - WELL LOGGING
HYDROLOGY (X,Y,Z,T)
REGIONAL AND LOCAL
WELL TEST DATA
CONCEPTUAL RESOURCE MODEL* (X,Y,Z,T)
EXPLORATION (X,Y, Z,T)
BEST WELL LOCATIONS
(PRODUCTION, INJECTION)
TECHNIQUE RESPONSES
GENESIS
RESERVOIR ENGINEERING/ MANAGEMENT (X,Y,Z,T)
POROSITY, PERMEABILITY
FLUID FLOW
WELL PRODUCIBILITY
DECLINE , LONGEVITY
RECHARGE
REINJECTION/ INJECTION
OPTIMUM FIELD DEVELOPMENT
WELL COMPLETION
CHEMICAL INTERACTION
* MODEL EXISTENCE:
MAPS
SECTIONS
COMPUTER
DOCUMENTS
INTEGRATED IN THE MINDS OF A FEW GEOSCIENTISTS AND ENGINEERS WORKING TOGETHER
X,Y,Z, = SPACE
T = TIME

Figure 3

INDUSTRY COUPLED PROGRAM DATA PACKAGES

AREA	BALTAZOR	TUSCARORA	MC COY	LEACH H.S.	COLADO	BEOWAWE	BEOWAWE	SAN EMIDIO	SODA LAKE	STILLWATER	DIXIE VALLEY	DESERT PEAK	HUMBOLDT H.	COVE FORT-SULPHURDALE UTAH	ROOSEVELT HOT SPRINGS UTAH
COMPANY	EPP	AM	AM	AO	G	G	C	C	C	U	SR	P	P	U	*
DATA															
GRAVITY	E	X	X	E	E	X		E		E		E	E	E	
GROUND MAG.					E	X						E			
AERO MAG.	E	X	X				E				E			E	E
ELEC. RES.					E	X	E	E	E	E				E	X
MAGNETO-TELLURIC		X	X	X	E		E		E	E	E	E	E		
AUDIO MAGNETO TELLURIC					E										
SELF POTENTIAL		X	X				E	E							
SEISMIC EMISSIONS							E	E						E	X
MICRO-EARTHQUAKE	E	X	X				E								
SEISMIC REFL. (weight drop)							E		E					E	
SEISMIC REFL. (CDP 12 or 24 fold)			X	X			X	E	E						X
GEOLOGY	E			E				E			E X	E	E	E	X
GEOCHEMISTRY	E			E							E			E	
SHALLOW TEMPERATURE											X				
SHALLOW THERMAL GRADIENT	E	E X	E X	X	E X	X		E	E	E	E			E	E X
DEEP THERMAL GRADIENT	X	X	X	X	X	X			E X		E X	E		E	X
EXPLORATION WELL ✣	X	X	X	X	X	X	E	E	E	E	X	X	X	E X	E X
FLOW TEST (if appropriate)	X	X	X	X	X	X	X			X	X	X	X	X	X

COMPANY EXPLANATION

EPP – Earth Power Production
AM – Amax Exploration Inc.
AO – Aminoil USA, Inc.
G – Getty Oil Co.
C – Chevron Resources Co.
U – Union Oil Co. of Ca.
SR – Southland Royalty Co.
P – Phillips Petroleum Co.

E = *EXISTING DATA*   X = *NEW PROGRAM*

* Companies at Roosevelt Hot Springs:

Getty Oil Co.
Thermal Power Co.
Geothermal Power Co.
Seismic Exploration Inc.
Geophysical Services Inc.
University of Denver (DRI)

✣ Exploration Wells -- Drill cuttings and geophysical well logs provided

INDUSTRY COUPLED PROGRAM

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

NEVADA

Baltazor
Beowawe
Colado
Desert Peak
Dixie Valley
Humboldt House
Leach Hot Springs
McCoy
San Emidio
Soda Lake
Tuscarora

UTAH

Cove Fort - Sulphurdale
Roosevelt Hot Springs

- COMPANIES INVOLVED

AMAX
AMINOIL
CHEVRON
EARTH POWER PRODUCTION
GEOTHERMAL POWER
GETTY
PHILLIPS
SOUTHLAND ROYALTY
THERMAL 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

DIRECT VS INDIRECT DETECTION

DIRECT METHOD - TEMPERATURE MEASUREMENT
SPRINGS AND WELLS

INDIRECT METHODS - HEAT FLOW STUDIES
- GRADIENT EXTRAPOLATION
- CHEMICAL GEOTHERMOMETRY
- GEOLOGIC MAPPING
- GEOPHYSICAL SURVEYS
- GEOCHEMICAL SURVEYS
- HYDROLOGIC STUDIES

REGIONAL EXPLORATION APPROACH

GEOLOGICAL

Structural mapping and analysis

GEOPHYSICS

Gravity

Aeromagnetic surveys

Regional electrical methods

Earthquake/microseismic

Heat flow measurements

GEOCHEMICAL

Trace element analysis

Isotope studies

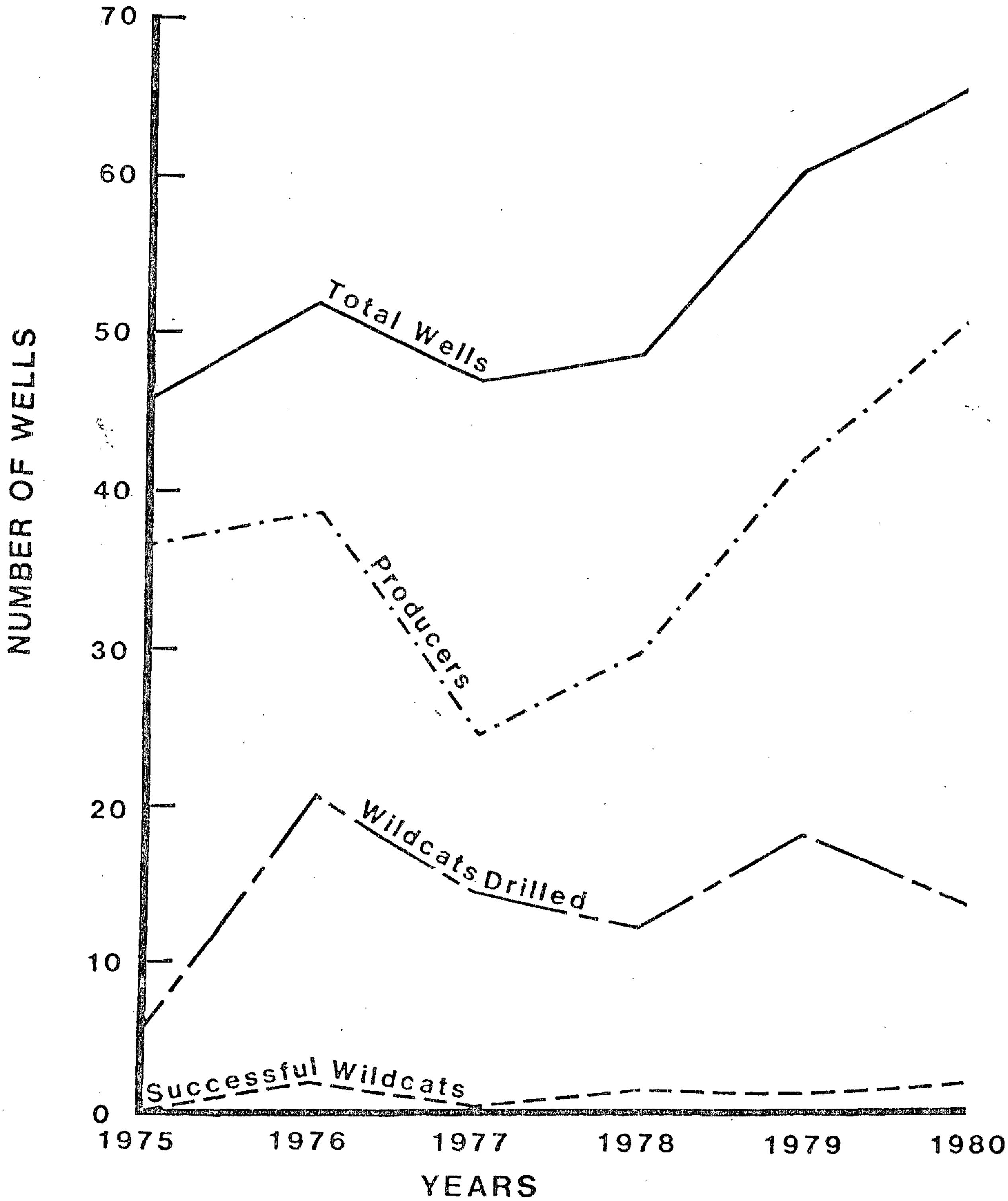
DRILL TESTS

EAT-002

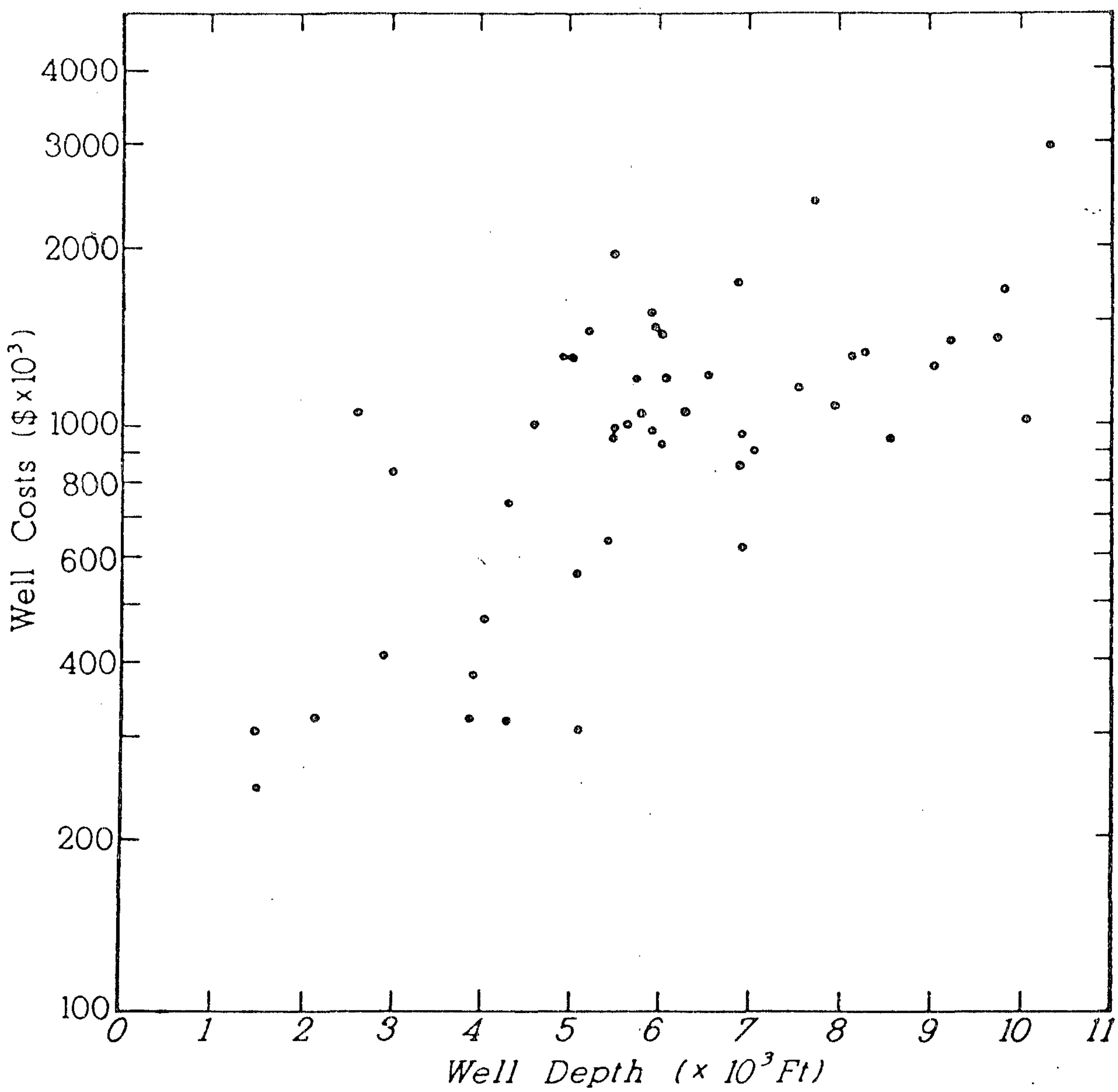
EXPLORATION AND EVALUATION SEQUENCE

Stage	Activities	Per Prospect Cost, $ K
RECONNAISSANCE (Prospect Selection)	Geologic Mapping Hot Springs & Wells	10
PROSPECT RANKING	Geologic Mapping Geothermometers Geophysics	30
LAND ACQUISITION & DETAILED EXPLORATION (To site wildcat well)	Geologic Mapping Hg, As Surveys Electrical Geophysics Gradient Drilling Data Synthesis	300
WILDCAT DRILLING (Reservoir Confirmation)	Lithologic Logging Geophysical Well Logging	2,000
DETAILED EVALUATION (To site step-out wells)	Electrical Geophysics Seismic Survey Geochemistry Gradient Drilling Data Synthesis	600
STEP-OUT DRILLING (To delineate reservoir)	Lithologic Logging Geophysical Well Logging	6,000
[PERMITTING] PRODUCTION DRILLING (55 MWe)		30,000
		$38,940 K

UNSUCCESSFUL PROJECTS → FILES



GEOTHERMAL WELLS DRILLED
(1975-1980)



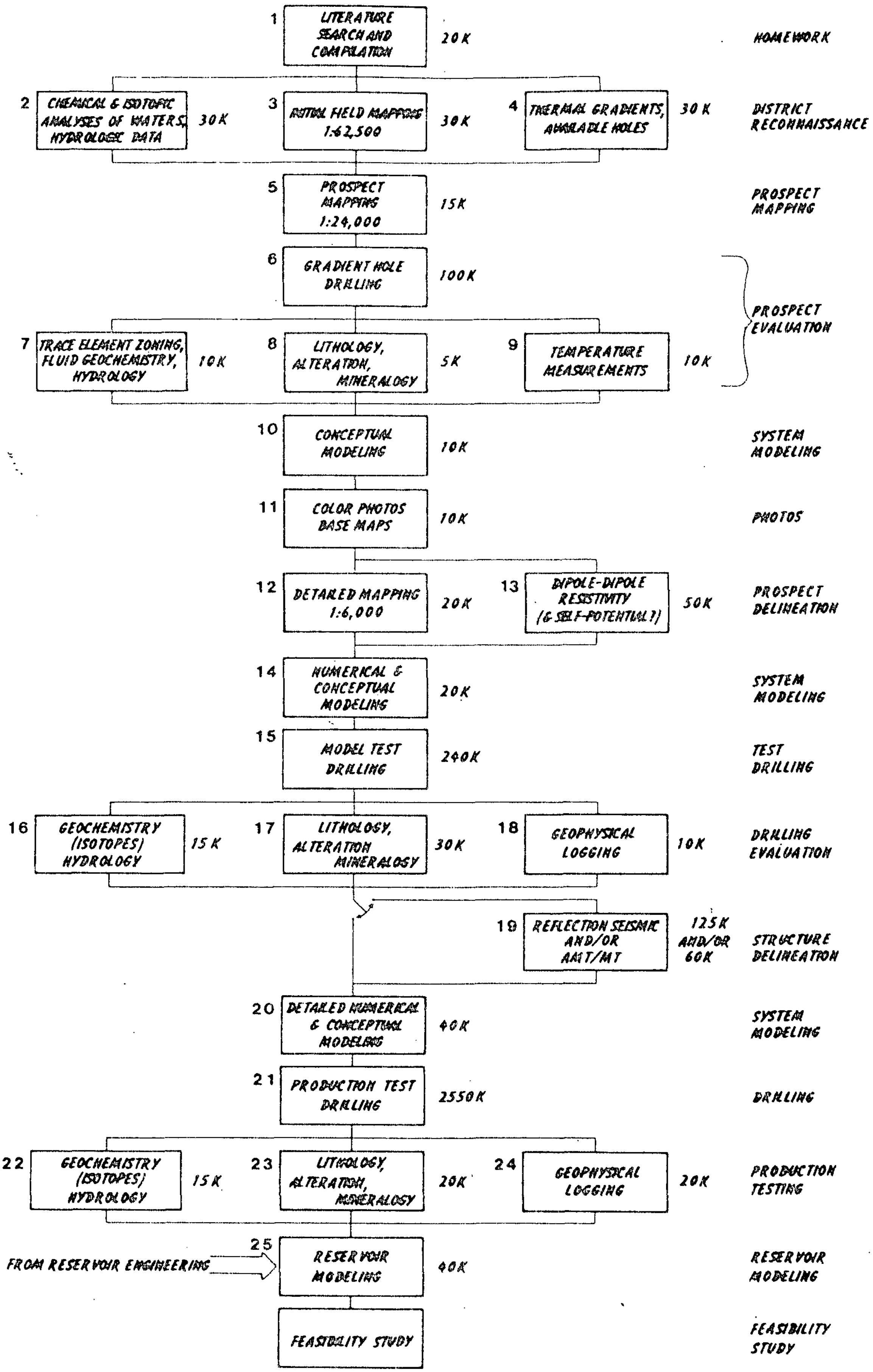
Well cost [1979 $] vs Depth for 50 geothermal wells

GEOTHERMAL EXPLORATION AND ASSESSMENT TECHNOLOGY PROGRAM

PROGRAM OBJECTIVES

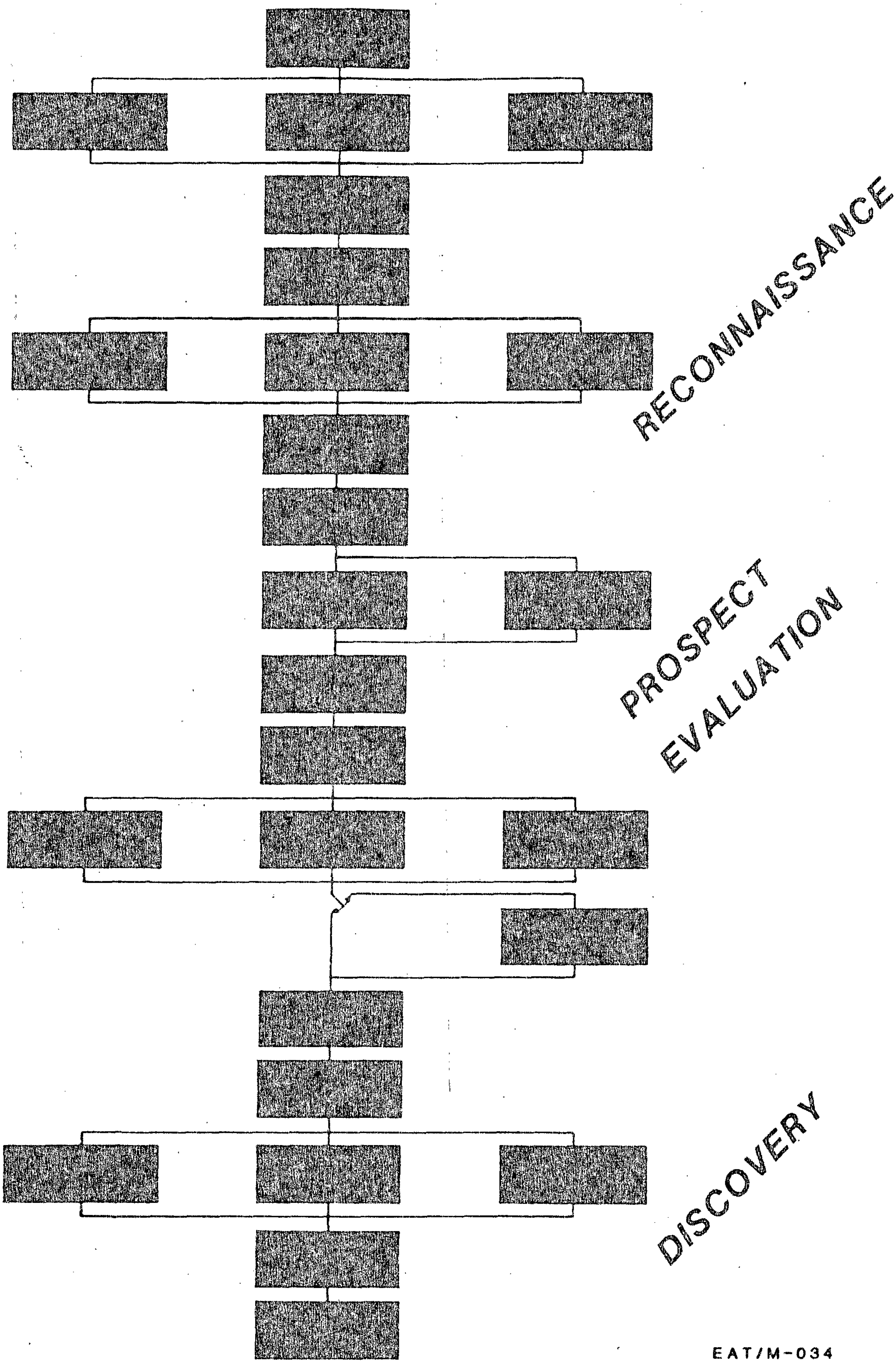
- Improve cost effectiveness of exploration
- Improve methods for siting exploratory wells
- Improve methods for siting step-out, evaluation wells
- Improve effectiveness of drilling
- Improve ability to delineate & characterize reservoir
- Transfer technology

SUGGESTED HIGH TEMPERATURE HYDROTHERMAL EXPLORATION STRATEGY

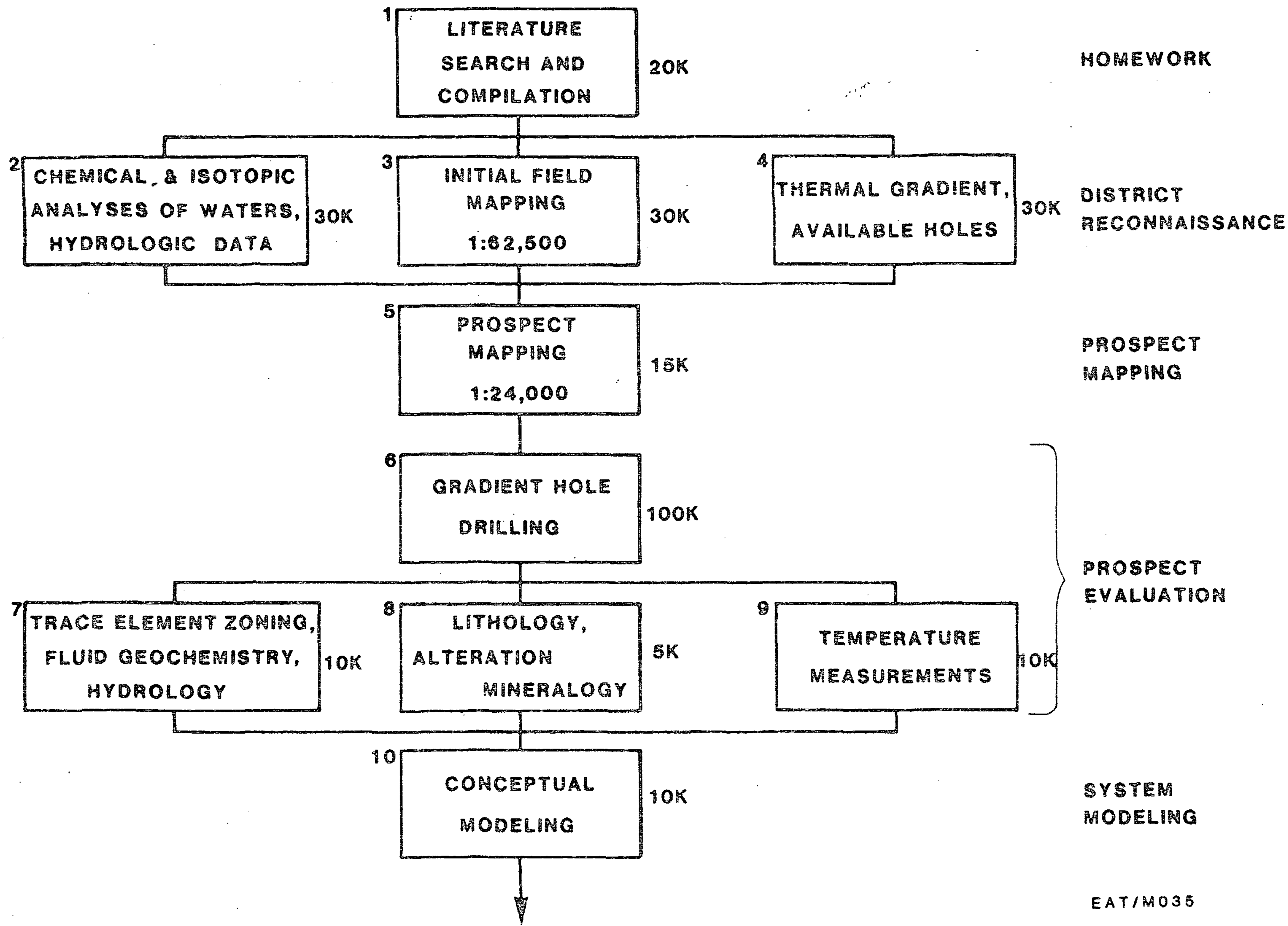


GG-031a

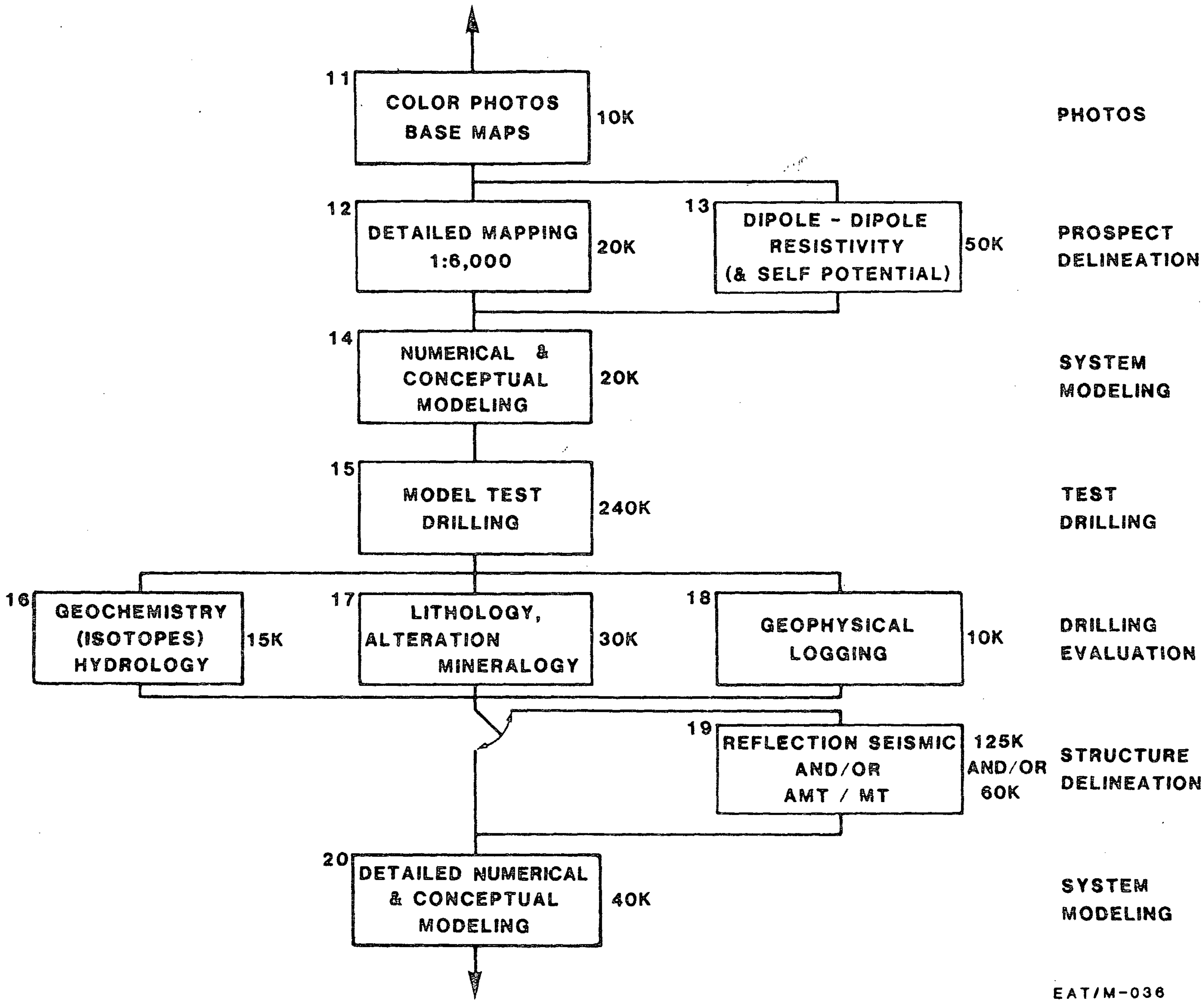
SUGGESTED HIGH TEMPERATURE HYDROTHERMAL EXPLORATION STRATEGY

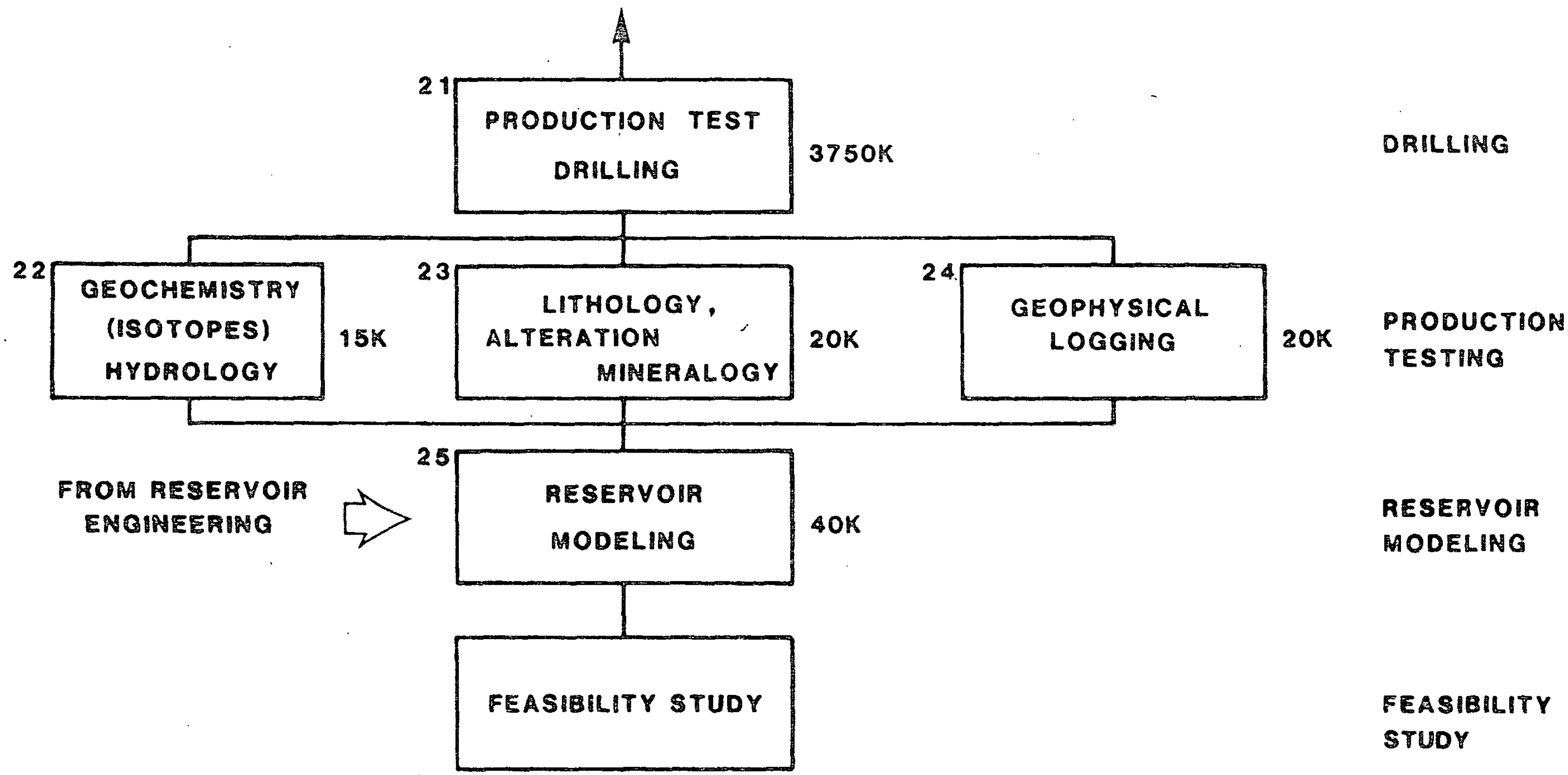


EAT/M-034


1 LITERATURE SEARCH AND COMPILATION
20K
HOMEWORK
2 CHEMICAL & ISOTOPIC ANALYSES OF WATERS, HYDROLOGIC DATA
30K
3 INITIAL FIELD MAPPING 1:62,500
30K
4 THERMAL GRADIENT, AVAILABLE HOLES
30K
DISTRICT RECONNAISSANCE
5 PROSPECT MAPPING 1:24,000
15K
PROSPECT MAPPING
6 GRADIENT HOLE DRILLING
100K
7 TRACE ELEMENT ZONING, FLUID GEOCHEMISTRY, HYDROLOGY
10K
8 LITHOLOGY, ALTERATION MINERALOGY
5K
9 TEMPERATURE MEASUREMENTS
10K
PROSPECT EVALUATION
10 CONCEPTUAL MODELING
10K
SYSTEM MODELING

EAT/M035


11
COLOR PHOTOS
BASE MAPS
10K
PHOTOS
12
DETAILED MAPPING
1:6,000
20K
13
DIPOLE - DIPOLE
RESISTIVITY
(& SELF POTENTIAL)
50K
PROSPECT
DELINEATION
14
NUMERICAL &
CONCEPTUAL
MODELING
20K
SYSTEM
MODELING
15
MODEL TEST
DRILLING
240K
TEST
DRILLING
16
GEOCHEMISTRY
(ISOTOPES)
HYDROLOGY
15K
17
LITHOLOGY,
ALTERATION
MINERALOGY
30K
18
GEOPHYSICAL
LOGGING
10K
DRILLING
EVALUATION
19
REFLECTION SEISMIC
AND/OR
AMT / MT
125K
AND/OR
60K
STRUCTURE
DELINEATION
20
DETAILED NUMERICAL
& CONCEPTUAL
MODELING
40K
SYSTEM
MODELING
EAT/M-036



21
PRODUCTION TEST DRILLING
3750K
DRILLING
22
GEOCHEMISTRY (ISOTOPES) HYDROLOGY
15K
23
LITHOLOGY, ALTERATION MINERALOGY
20K
24
GEOPHYSICAL LOGGING
20K
PRODUCTION TESTING
25
FROM RESERVOIR ENGINEERING
RESERVOIR MODELING
40K
RESERVOIR MODELING
FEASIBILITY STUDY
FEASIBILITY STUDY

EAT/M-037

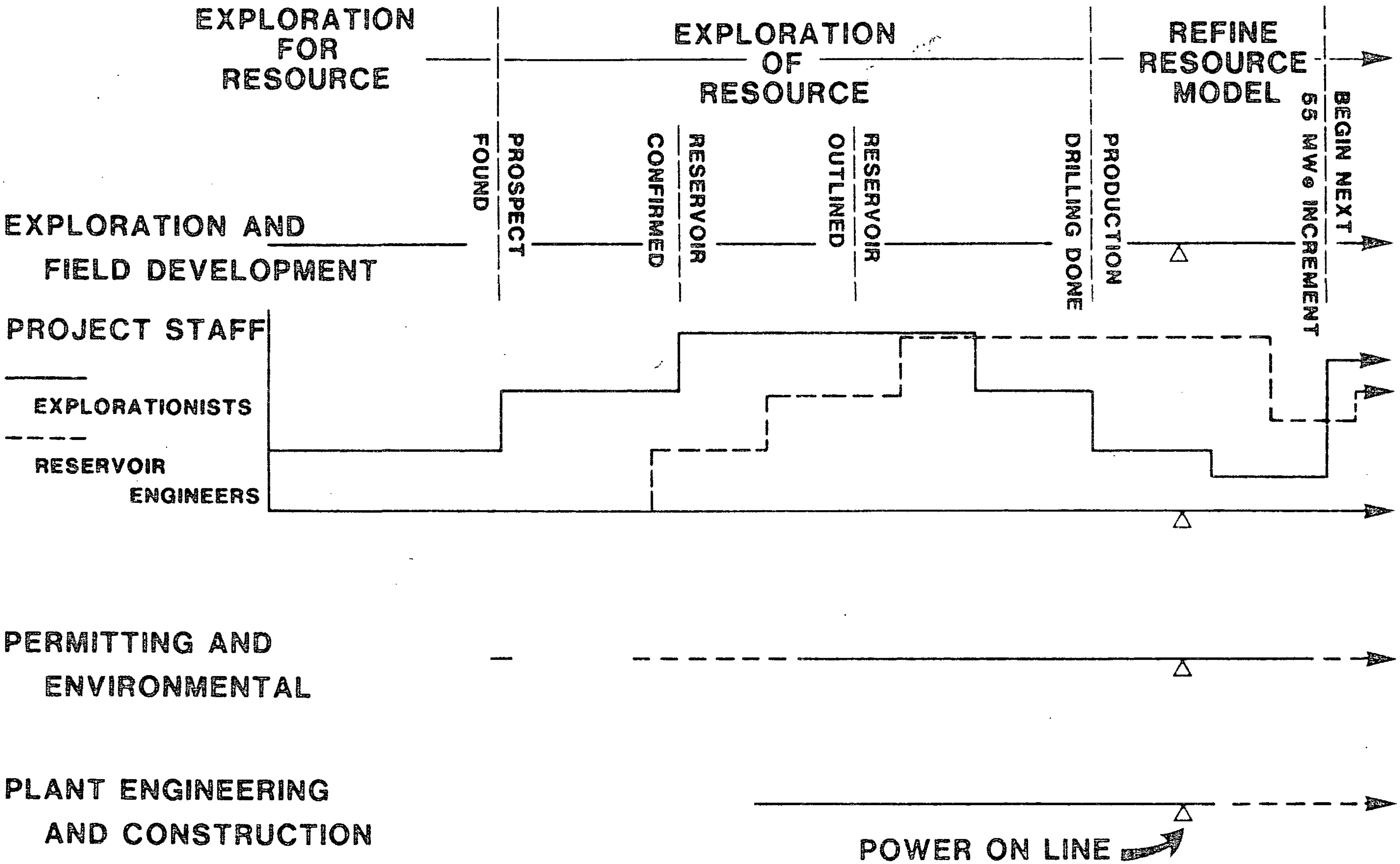
TYPICAL EXPLORATION COSTS

Water analyses	\$100-\$200/sample
Surface geochem.	\$30-\$200/sample
Volatile geochem.	~\$20/sample (Rn, Hg)
Temperature gradient holes	\$10-\$100/foot
Electric methods	\$200-\$2000/line mile
Magnetics	\$8-\$25/line mile (airborne) \$200/line mile (ground)
Seismic	\$5000-\$10,000/line mile
Gravity	\$30-\$70/station
Logging	\$2000-\$20,000/hole
Drilling production hole	*\$500,000-\$1,000,000 (or more) to \$275/foot in lower 48 (\$1000/foot in Alaska)*

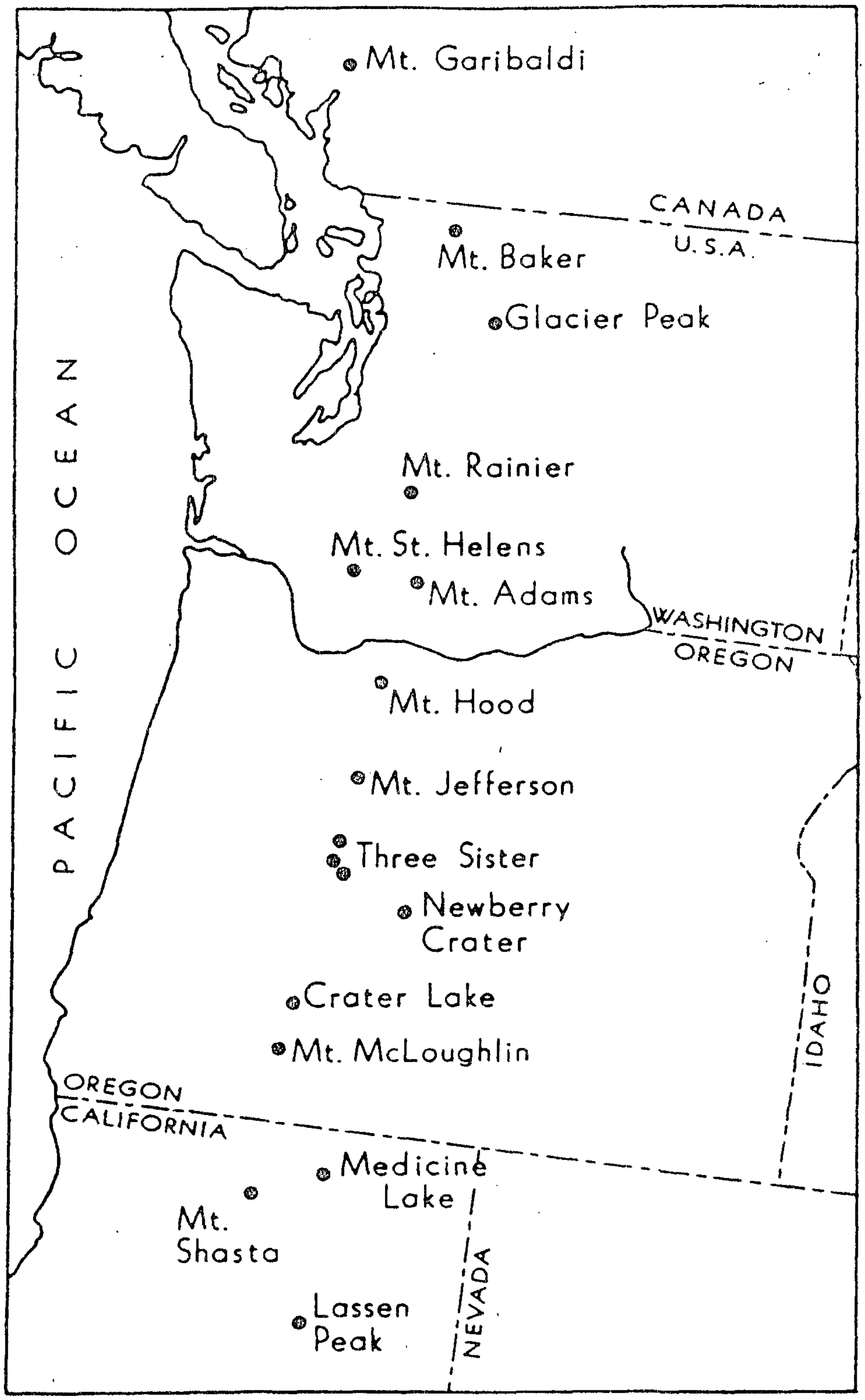
(modified from GRC)

EXPL/F-006

RESOURCE DEFINITION STAFF



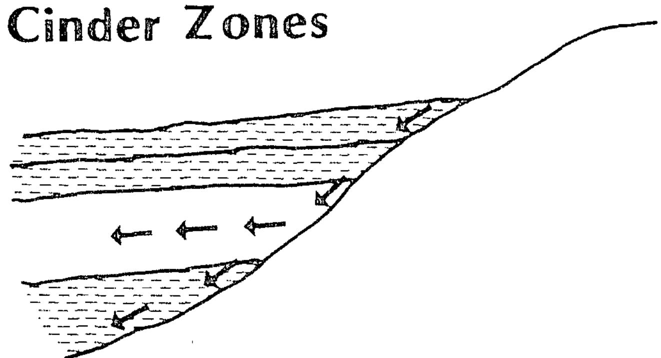
PR-03


Mt. Garibaldi
CANADA
U.S.A.
Mt. Baker
Glacier Peak
PACIFIC OCEAN
Mt. Rainier
Mt. St. Helens
Mt. Adams
WASHINGTON
OREGON
Mt. Hood
Mt. Jefferson
Three Sister
Newberry Crater
Crater Lake
Mt. McLoughlin
IDAHO
OREGON
CALIFORNIA
Medicine Lake
Mt. Shasta
Lassen Peak
NEVADA

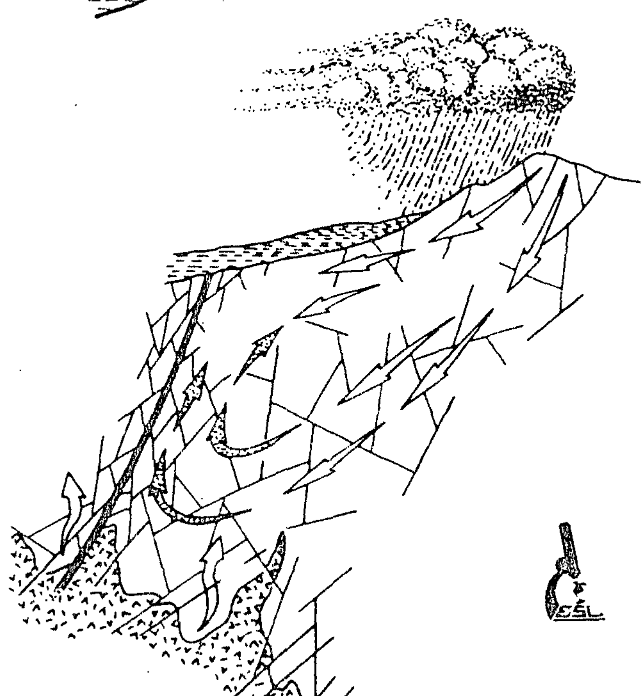
ASCENSION GEOTHERMAL PROGRAM

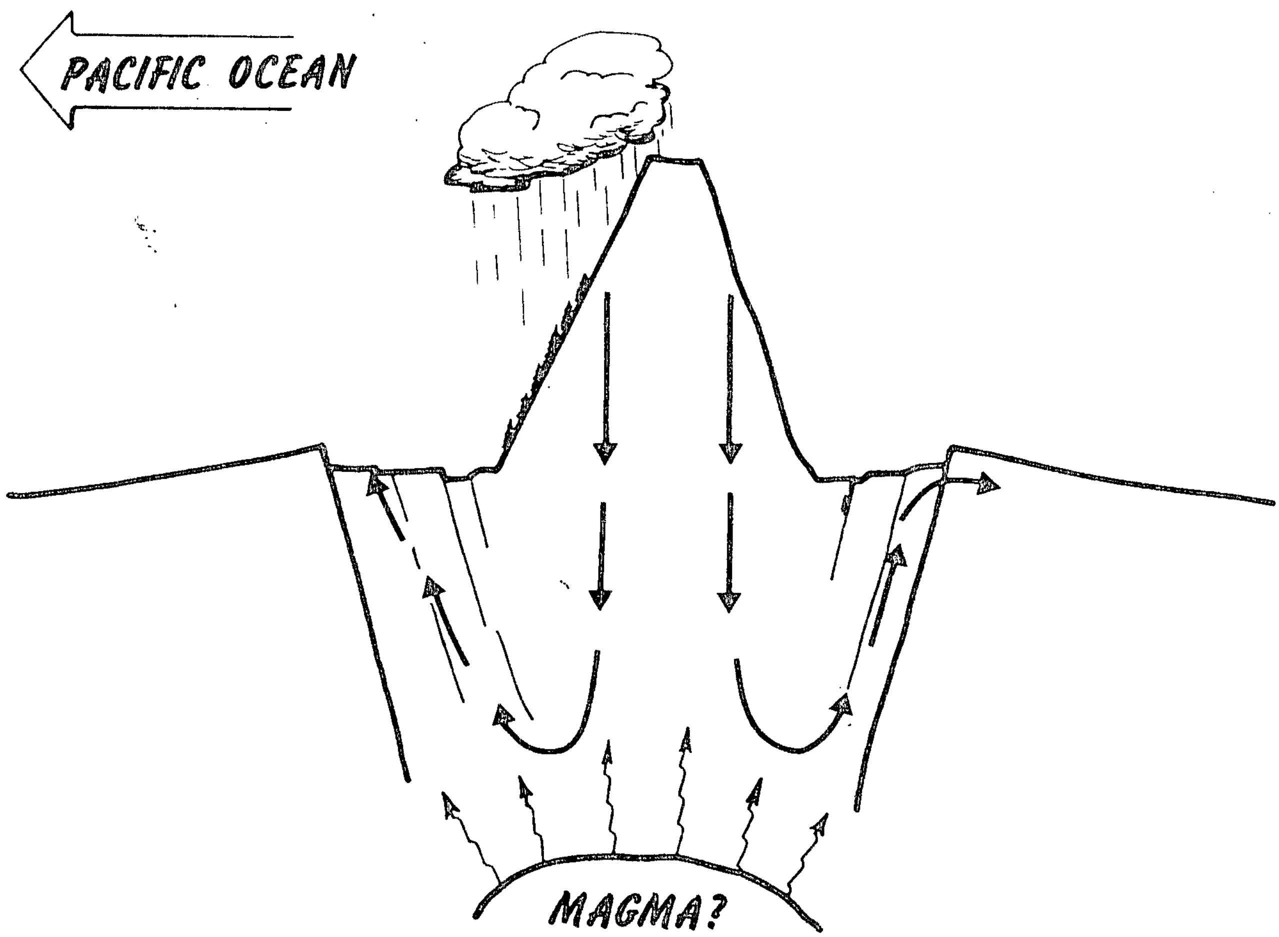
PERMEABILITY

- Original Flow Breccias & Cinder Zones
  - Interbedded Sandstones
  - Contacts



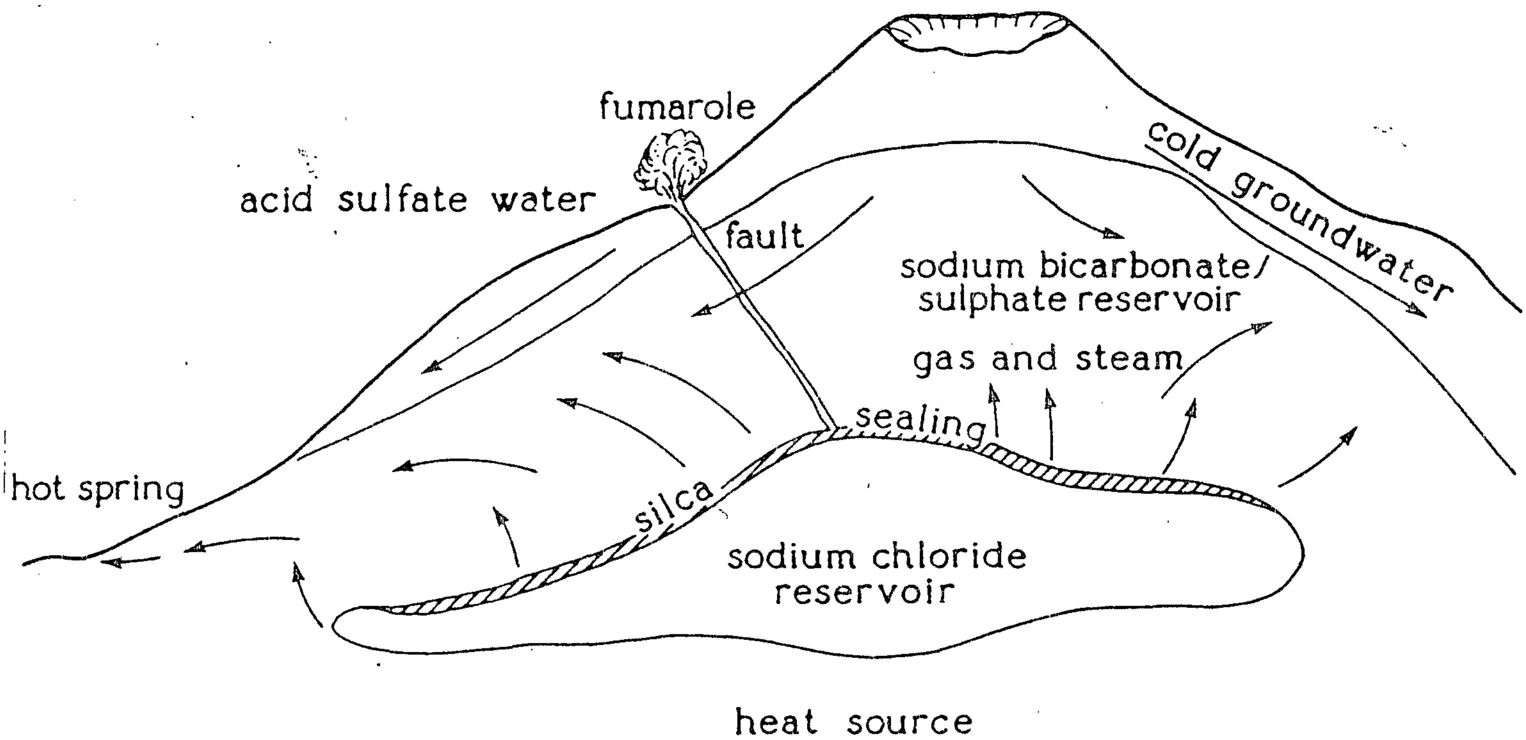
- Faults & Fractures





GEOTHERMAL SYSTEM ASSOCIATED WITH A VOLCANIC BELT

GG-009


fumarole
acid sulfate water
fault
cold groundwater
sodium bicarbonate/
sulphate reservoir
gas and steam
sealing
hot spring
silca
sodium chloride
reservoir
heat source

MEAGER CREEK GEOTHERMAL AREA

- UNRESTRICTED ACCESS TO ALL PROPRIETARY DATA
  - REPORTS
  - UNPUBLISHED GEOLOGIC LOGS
  - UNPUBLISHED FLUID DATA
  - GEOPHYSICAL LOGS
- CORE FROM THERMAL GRADIENT AND DEEP PRODUCTION WELLS
- COMPLETE SUITE OF CHIP SAMPLES FROM THE THREE 3500 METER DEEP PRODUCTION WELLS
- EXTENSIVE AMOUNT OF FLUID DATA AVAILABLE
- INTIMATE FAMILIARITY WITH DATA

October 2, 1987

Geothermal Discussion

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