GL01824

DEVELOPMENT OF GEOTHERMAL EXPLORATION STRATEGIES
FOR THE
CASCADES VOLCANIC PROVINCE

SUGGESTIONS FOR PROGRAM PLANNING

for

U. S. Department of Energy
San Francisco Operations Office

by

Earth Science Laboratory
University of Utah Research Institute

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CONTENTS

2.0 INTRODUCTION

U. S. Geological Survey Circular 790 (Muffler et al., 1978) states that the identified accessible hydrothermal resource base in the Cascades province is estimated to be 57 quads, whereas the undiscovered, accessible base is crudely estimated to be twenty times this amount, of 1140 quads. Estimates such as these are recognized as being quite rough at the present time because of lack of hard data. There are few discovered resources. However, the geologic setting of the Cascades province lends credence to the idea of a large resource base, and it is on this promise that industry has proceeded with limited exploration.

Industry progress, however, has not been rapid, and it appears that industry will continue to be reluctant to spend much money on Cascades exploration unless clear-cut ideas can be developed of the discovery potential and of cost-effective exploration methods. Beyond that, proof of economic viability will require thorough exploration and testing of any resource discovered. It is clear that stimulation of development in the Cascades is needed and that the promise of pay back of federal research funds is substantial.

3.0 BACKGROUND

The abundance of young volcanic rocks and the isolated occurrences of thermal springs along the Cascades range suggest that a large geothermal resource base may exist. It is probable that Cascade Mountains overlie a subduction zone, and magma generated at depth rises into the crust transporting large amounts of heat into the upper crust under the range. In spite of these favorable geologic capabilities, few hydrothermal resources have been discovered as compared to the widespread occurrence of heat sources. Precipitation is high over much of the area, and the resulting abundance of shallow cold water is likely to be masking underlying convection systems.

Geothermal systems in the Cascades have remained elusive exploration targets, with confirmed high-temperature resources present only at Meager Creek in British Columbia, Newberry Caldera in Oregon, and Lassen Peak in California. Numerous reasons have been proposed for the apparent lack of geothermal systems in this province rich in volcanic heat sources, including the proposition that geothermal systems are not present. If they are present, it is clear that exploration will be both expensive and risky. The risk and expense can each be mitigated somewhat through the development of application of valid exploration strategies. Each strategy must be developed and applied with cost in mind, progressing from less expensive methods early in the program to more expensive methods utilized to site expensive production-scale wells. In this way, the financial risk can be limited.

Although few high-temperature geothermal systems are known in the Cascades Province, producing geothermal systems occur in similar geologic settings in other parts of the world. These include the Neovolcanic Belt of Mexico, the volcanic belt of Central and South America, and the island arc environments of New Zealand, Japan, Indonesia, and the Philippines. Data are available for most of these environments that can be used in establishing conceptual models for geothermal systems in andesitic volcanic environments in general. In addition, abundant data are available for fossil hydrothermal systems in these environments, that is, hydrothermal ore deposits in subvolcanic settings. These data can provide valuable information on the character of fracturing, faulting and hydrothermal processes in such environments with important bearing on subsurface processes occurring today in active hydrothermal systems.

During the past five years, the U. S. Geological Survey, working partly under funding provided by DOE-DGHT, has been conducting fundamental earth science studies in the Cascades region aimed at obtaining a better understanding of the geothermal resources. Most of this work has been regional in nature. It has consisted of collection and interpretation of a large variety of data including geologic mapping, aeromagnetic surveys, gravity surveys, active and passive seismic surveys and geochemical studies. These data have been evaluated largely in terms of developing a regional geologic picture and have been applied specifically in only a few areas. The results of this work, as well as the basic data and to a certain extent the USGS personnel working on the project, will be available to researchers on the present program and will provide substantial assistance.

In an effort to stimulate geothermal development in the Cascades region of the United States, the U.S. Department of Energy is sponsoring the Cascades Thermal Gradient Drilling Program. Geothermal development in the Cascades has been limited by the paucity of surface thermal expressions, perhaps resulting from extensive cold water flushing of near-surface aquifers. The objective of

DOE's program is to sample thermal zones beneath the influence of the near-surface cold aquifers. Proposals have been solicited by the Idaho Operations Office for the drilling of intermediate-depth thermal gradient holes with DOE sharing as much as 50 percent of the cost. For their contribution, DOE requires that certain samples and data be collected, including but not limited to, the following: geophysical well logs, cuttings and core samples, and fluid samples. The data would be released to the public to further stimulate exploration interest. In addition, it is expected that State Geothermal Resource Assessment Teams would conduct field studies in the areas of drilling, and that this work would contribute valuable site-specific information to the project through topical reports.

The Cascades Thermal Gradient Drilling Program is expected to contribute materially to knowledge of heat flow and other aspects of potential Cascades geothermal environments. Data generated from this program will require integration into available data bases, and interpretation and publication in order to maximize their utility to industry and stimulate geothermal development. The program of work proposed below is designed to maximize results from the impending Cascades Thermal Gradient Drilling Program.

We have previously proposed an exploration strategy for the Basin and Range Province (Ward, Ross and Nielson, 1981) which utilized our experience with DOE's Industry Coupled Drilling Program. That strategy began with a conceptual model of the resource and then applied specific exploration methods to both locate the resource and update the conceptual model. These methods were applied with cost in mind, progressing from the less expensive methods early in the program to more expensive methods utilized to site expensive production-scale wells. In this way, the financial risk is decreased since the prospect can be dropped at any time prior to the application of a more expensive method.

We propose to apply existing data bases, the new data to be generated under DOE's Cascades Thermal Gradient Drilling Program, and our experience with geothermal exploration programs and techniques to formulate an exploration strategy for the Cascades Province.

4.0 DEFINITION OF PROBLEMS

Although from a scientific viewpoint there are numerous interesting questions to be answered in the Cascades, from a practical exploration viewpoint, as industry sees its problems, they can be summarized in such pragmatic questions as stated below.

1. What is the potential for occurrence of undiscovered, economic hydrothermal resources in the Cascades?
2. Where, specifically, are hydrothermal systems most likely to be found with respect to visible geologic features and other geoscientific data that can be obtained on the surface?
3. Which of the available exploration techniques can be fruitfully applied to discovery and assessment of hydrothermal resources, and how can exploration techniques be improved?
4. How can cost and risk be minimized during hydrothermal development, i.e. what are the most cost effective exploration and resource assessment strategies?

Potential for Occurrence

At the present state of knowledge, we know that there are substantial sources of heat in the crust in the Cascades because of the long volcanic history of the region, a history which continues to the present day. We suspect that the Cascades may be underlain at depth by intrusions of 1/4 to 10 sq mi or more that have been emplaced at different times during the past 10 million years. We do not know the range in depths of magma chambers large enough to be interesting as resource/geothermal heat. By analogy with eroded areas, where we can now see the roots of former volcanos, we suspect that the intrusions have a tendency to cluster due to repeated injection of magma along certain lines of preferred upward mobility or due to more vigorous generation of magma beneath certain areas. Also by analogy with eroded areas, we know that active hydrothermal convection systems will exist in association with only some intrusions and then only on certain parts of these intrusions. How, then, do we ascertain the frequency of occurrence of hydrothermal systems presently hidden?

Location of Hydrothermal Systems

Clearly, at our current stage of development, we should confine our exploration to the youngest volcanic features--the active and recently active volcanic areas. Beyond that, little is known. Where, specifically, relative to a surface volcanic feature will a hydrothermal system most likely be. The Three Sisters field in central Oregon, for example, comprises perhaps 150 sq mi, whereas a viable geothermal system might occupy 2 sq mi. Drill testing of each square mile is a possible exploration method, but is not financially feasible. How does one pick the best 2 sq mi to drill test? We cannot answer this question--and we do not even know how deep we must drill.

Application and Improvement of Exploration Techniques

Many potential exploration techniques exist, but the applicability of few is known. In addition, there are practical problems due to topography and limited access in applying some techniques. Is a helicopter supported resistivity survey cost effective? Can the seismic method be used effectively? Do hydrothermal systems at depth relate to geologic structures that can be mapped on the surface?

There are two needs in order to evaluate and improve exploration techniques. They are: (1) areas where techniques can be tested and funds to test them, and (2) conceptual geologic models from which the expected responses of a hydrothermal system can be predicted. Appropriate areas for technique testing exist, but to date little testing has been done. No reliable conceptual resource models exist.

Minimizing Cost and Risk

Cost and risk can be minimized if exploration strategies can be devised that minimize the amount of exploration work needed to site successful drill holes while at the same time maximizing odds of success. To devise such exploration strategies, we need solid conceptual resource models and a variety of exploration tools that work.

Key Problems

A number of key problems can be listed whose answers would assist very substantially in furthering geothermal development in the Cascades.

Geological Problems.

1. Do sizable heat sources (magma bodies) exist in the shallow crust (< 10 km) in the Cascades, where and at what depth?
2. How do surface volcanic manifestations relate to shallow crustal intrusions?
3. Is surface geologic mapping of lithology and structure pertinent to locating hydrothermal resources in the Cascades?

Geochemical Problems.

1. Is the geochemistry of thermal and non-thermal springs pertinent to locating hydrothermal resources in the Cascades?
2. Is knowledge of hydrothermal alteration on the surface and in shallow thermal gradient drill holes pertinent to locating hydrothermal resources in the Cascades.

Geophysical Problems.

1. Would a Cascades-type hydrothermal system be expected to yield an anomaly detectable at the surface on a magnetic, galvanic resistivity, MT or AMT, CSEM, seismic or other geophysical survey?
2. As a rule, how deep is the so-called "rain curtain", beneath which one must presumably drill to get valid heat flow/thermal gradient data?
3. Can geophysics be of assistance in mapping surface and/or subsurface geology?

Hydrological Problems.

1. How can the "rain curtain" effect be evaluated for specific areas?
2. What are the expected fluid flow patterns for hydrothermal systems in the Cascades?

5.0 PROJECT OBJECTIVES AND STRATEGIES

The objectives of the proposed research are as follows:

1. Establish valid conceptual geologic models of Cascades hydrothermal resources;
2. Improve and test exploration methods and techniques, and,
3. Establish valid exploration strategies that minimize risk and cost in developing Cascades hydrothermal resources.

A number of strategies are appropriate to reaching these objectives. Among these are:

1. Direct the research work at the key geoscience problems that currently inhibit resource discovery and development in the Cascades;
2. Make maximum use of available data, both from the Cascades and from other geologically analogous areas;
3. Cooperate to the maximum extent with industry and other organizations seeking geothermal resources in the Cascades;
4. Make optimum use of talents at UURI and recognize and cooperate with programs conducted by other groups.

Statement of Work

Task 1 - Planning Assistance. UURI will provide DOE and other designated entities, such as BPA, with assistance as requested in planning research activities, exploration programs and technology transfer.

Task 2 - Literature Review. The available literature for the Cascades province and for geothermal systems in similar settings, including hydrothermal ore deposits, will be reviewed. This review will concentrate on 1) the establishment of conceptual models of geothermal resources in this environment, and 2) the application and success of various exploration methods in defining or locating these systems.

Task 3 - Data Compilation and Reduction. Numerous geophysical surveys have been completed in the Cascades. In particular, aeromagnetic and some electrical resistivity data is available. This data will be acquired and analyzed to provide a determination of their potential effectiveness in the exploration for geothermal systems in the Cascades.

Task 4 - Integration and Interpretation of Data. The available information will be analyzed to form a conceptual model or series of conceptual models of Cascades-type geothermal systems.

Task 5 - Testing of Techniques and Models. We anticipate that there will be a need to acquire additional field geologic, geochemical and/or geophysical data for the purpose of testing either specific exploration techniques or specific ideas developed from conceptual models. Several test areas are readily available--among them are Newberry Caldera, Lassen Peak, Meager Creek, Mt. Baker, Glacier Peak and Mt. Rainier. Geothermal occurrences are known at each of these areas and each could become a focus for testing of ideas that would be applied to covered areas in the Cascades.

Task 6 - Aquifer Characterization. One of the key objectives of DOE's program is the evaluation of the effects of stacked aquifers and cold water flow that has been postulated in these aquifers, on surface geothermal manifestations. We propose to evaluate the extent of cold water overflow in each DOE-sponsored drill hole and in other available holes. We will obtain several temperature profiles in each hole until an equilibrium profile is obtained.

Another component will be to add chemical tracers to the drilling fluid in DOE-sponsored holes. These tracers will allow the determination of the amount of drill fluid contamination of water samples collected for chemical analyses and the calculation of chemical geothermometers. We propose to investigate hydrothermal alteration in drill chip and core samples to determine the maximum temperatures experienced by the rocks and compare those with the present temperatures measured in the holes.

Task 7 - Cascades Exploration Strategies. Using all of the information developed from the program, we will formulate optimum exploration strategies for the Cascades region. We will examine the contribution of each of the commonly used exploration and reservoir assessment techniques to siting discovery and step-out wells, and will evaluate cost effectiveness of each method. The results will be one or more suggested strategies, i.e. combinations of existing exploration techniques that appear to be the most effective in discovery and assessment of geothermal resources in the Cascades region.

Task 8 - Case Studies. To be of maximum use to geothermal developers in the Cascades, the data acquired through this program will be compiled into a case study of the entire program. This case study will include a review of existing literature, a discussion of the siting criteria used for the thermal gradient holes, and the results of topical reports, open-file data, and other geoscientific work done on each hole, both by us and by others.

Task 9 - Technology Transfer. It will be important to communicate results of the above work to industry, and a series of workshops and conferences will be conducted. Transactions of these meetings will be published to help document results. In addition, the results of these efforts will be presented at professional meetings and reports will be submitted for publication in professional journals.

"Roadmap #1"

SUGGESTED HIGH TEMPERATURE HYDROTHERMAL EXPLORATION STRATEGY

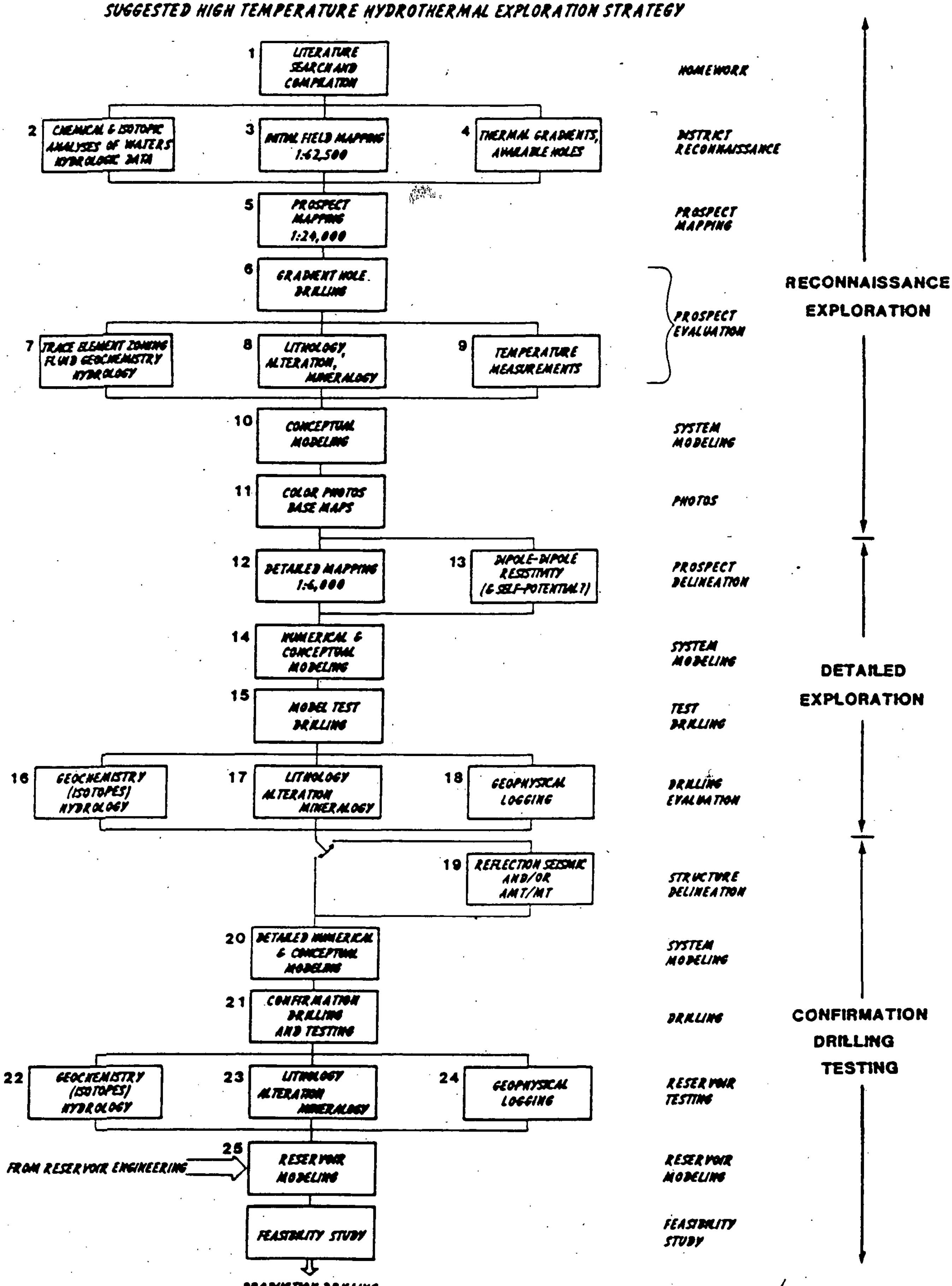
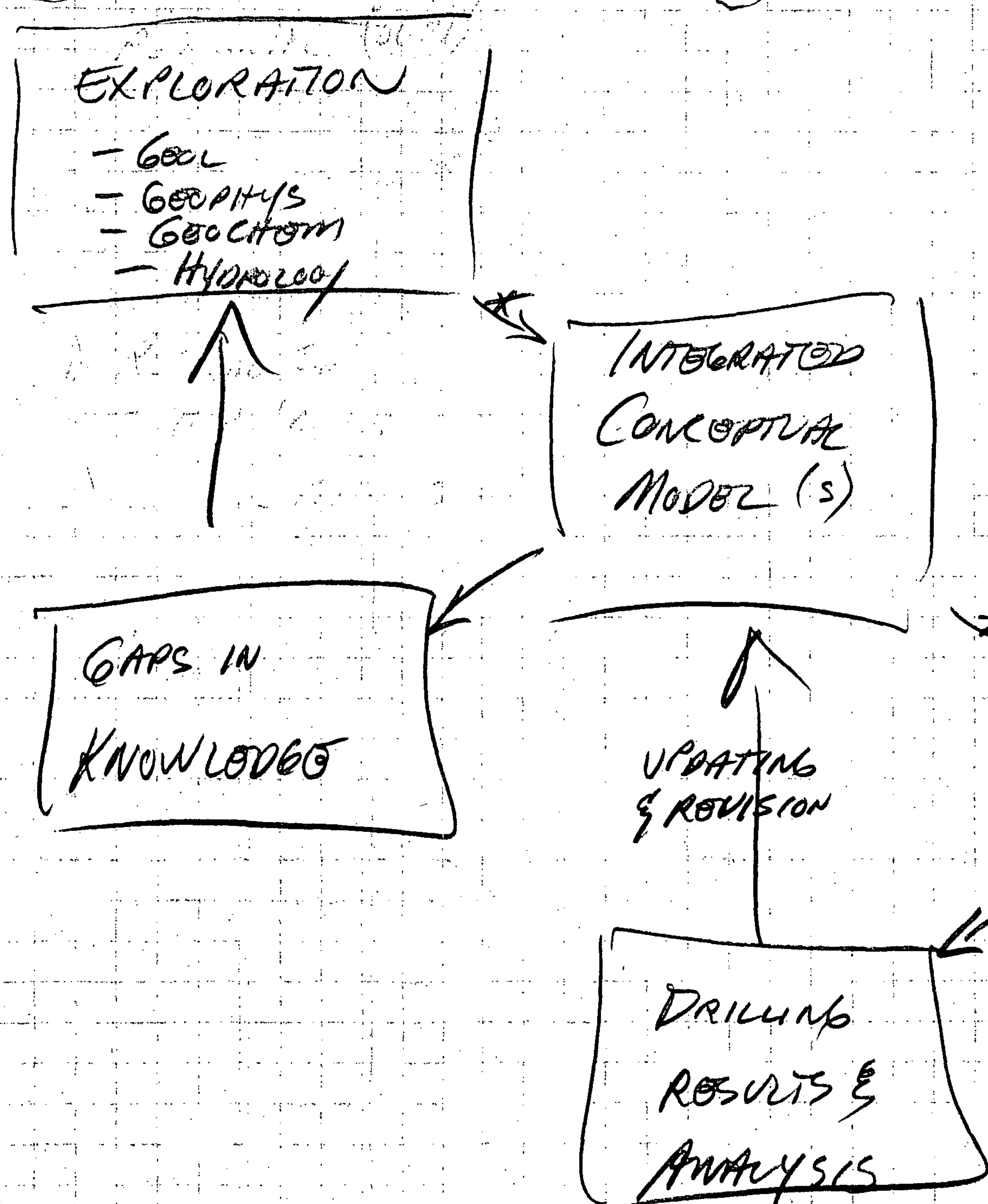


Figure 2

UURI/WRIGHT PROPOSAL TO DOE AUG. 31, 1983

CASCADES EXPLORATION STRATEGY



* SEQUENCE OF SITE SCREENING

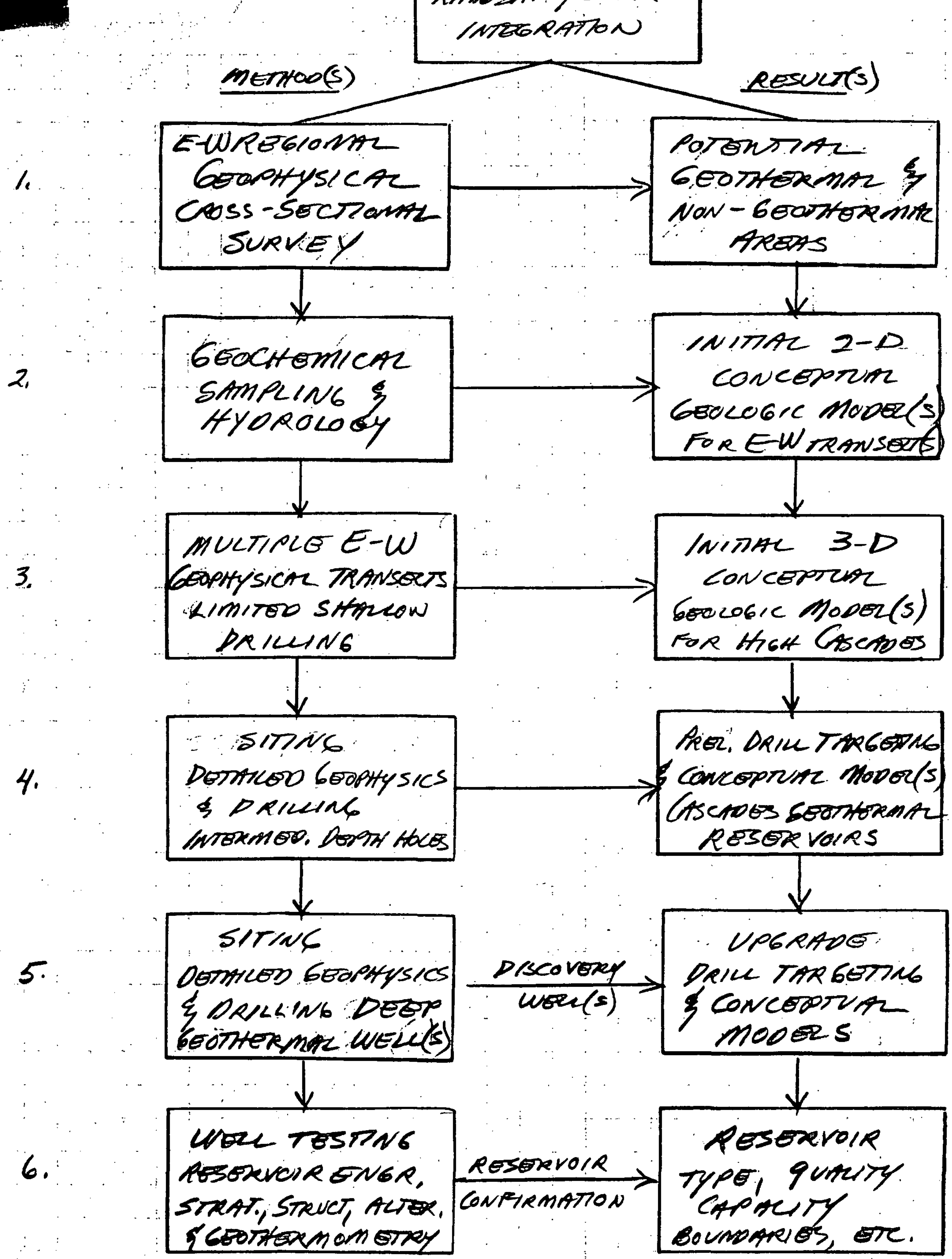
1. REGIONAL: HIGH CASCADES
   - NEWBERRY CALDERA
   - MEDICINE LAKE
2. POTENTIAL GEOTHERMAL PROSPECTS
   - 1,000 - 3,000' HOLES - ID
     ↓
   - ~6000' SLIM HOLES
     ↓
   - 10,000' ~~DEEP~~ HOLE(S)

FROM: LETTER TO ID / PRESTWICH / NICHOLS

DOE/MOLLOY
6-14-84

HIGH CASCADES GEOTHERMAL EXPLORATION STRATEGY

DOE/MOLLOY
10-26-84



HIGH CASCADES GEOTHERMAL EXPLORATION STRATEGY

DOE/MOLLOY
10-26-84

PHASE

(ROADMAP 1)

0. – PHOTOLINEAR/SLAR INTERPRETATION + EXISTING GEOLOGIC/HYDROLOGIC MAPS
– EXISTING PUBLICATIONS/EXPERTS → CONSOLIDATE & INTEGRATE KNOWLEDGE

RESULT • PRELIMINARY IDENTIFICATION OF POTENTIAL GT/NON-GT AREAS
(SELECTION OF OPTIMUM GEOPHYS. CROSS-SECTIONAL TRAVERSES)

1. REGIONAL GEOPHYSICAL CROSS-SECTIONAL SURVEYS (@ 90° TO STRUCTURES & INTRUS. AXI[S]
(FROM WESTERN HOT SPRINGS TO EASTERN MAJOR VOL[CANIC]
FEATURES eg NEWBERRY)

RESULT • INITIAL 2D CONCEPTUAL GEOLOGICAL MODEL
FOR HIGH CASCADES VOLCANICS + ASSOC. E & W FEATURES

2. ADD GEOCHEMICAL SAMPLING & HYDROLOGY + GAP-FILLING GEOPHYSICAL SURVEYS
(WITH LIMITED SHALLOW DRILLING, DOWNHOLE TEMP.)

RESULT • 2-D CONCEPTUAL GEOLOGIC MODEL FOR CASCADE CROSS-SECTION # 1

3. REPEAT 1 & 2 FOR TOTAL OF 3-6 CASCADE CROSS-SECTIONS
(WITH LIMITED SHALLOW DRILLING, DOWNHOLE TEM[P.]
RIGOROUS EXTENSION OF 2-D CONCEPTUAL MODEL N & S ALONG HIGH CASCA[DES]
– IDENTIFY MAJOR COMMONALITIES, CHANGES, TRENDS & DIFFERENCES –

RESULT • INITIAL 3-D CONCEPTUAL GEOLOGIC MODEL FOR HIGH CASCADES
(WESTERN HOT SPRINGS THROUGH INTRUSIVE AXIS TO MAJOR EASTERN FEATURES eg NEWBERRY)
• IDENTIFICATION OF POTENTIAL GEOTHERMAL AREAS & INDIVIDUAL PROSPECTS/RESERVOIR[S]
• PRELIMINARY DRILL TARGETING MODEL(S) FOR EACH GEOTHERMAL SITE

4. LOCATE INTERMEDIATE DEPTH DRILL-HOLE SITES FOR PRIORITY GT PROSPECTS
PROVE SITES WITH DETAILED GEOPHYSICAL SURVEYS, DEEP SOUNDING (& SHALLOW HOLES, IF NEE[DED])
REVIEW CONFIRMATION GEOPHYSICS AND DRILL INTERMED. DEPTH HOLES, IF SUSTAINED

RESULT • POSS. DISCOVERY WELL(S) AND PREL. CONCEPTUAL MODELS FOR HIGH CASCADE GT RESERVOIR[S]

CASCADE EXPLORATION STRATEGY (CONT.)

PHASE

5. (REVIEW & ASSESS RESULTS – RECYCLE THROUGH 3. & 4., ABOVE, AS NECESSARY)
   RESCREEN POTENTIAL GT AREAS & PROSPECTS (RESERVOIRS); RERANK PRIORITY
   IDENTIFY PRELIMINARY DEEP DRILL SITES TARGETED FOR GT RESERVOIRS
   UPGRADE DRILL TARGETING MODEL(S) FOR EACH ~~DEEP~~ GT DRILLSITE.
   COMMIT TO, AND DRILL, EACH DEEP WELL

RESULT • DISCOVERY WELL(S), CONFIRMATION AND DETAILING OF CONCEPTUAL GEOL. MODELS AND WELL TARGETING MODELS

OR, REVISION OF CONCEPTUAL/TARGETING MODEL(S) (PARTIAL SUCCESS/FAILURE) AND RECYCLING THROUGH STEPS 3, 4 & 5 ABOVE

RESELECTING INTERMEDIATE AND DEEP DRILL HOLE SITE(S)

6. • WELL TESTING AND PRELIMINARY RESERVOIR ENGINEERING:
   + DETAILED LITHOLOGY, STRUCTURE, ALTERATION, GEOTHERMOMETRY

RESULT • RESERVOIR TYPE, QUALITY, CAPACITY, BOUNDARY(S) ETC

DOWNONVILLE
SWANBERG

DOGAMI / George Priest
UURI / Mike Wright
BPA / John Geyer
USGS / Pat Muffler

Oct 26, 1984

Subject: Cascades Exploration Strategy.

I'm deliberately keeping this informal, because it is first cut, and needs creative input and constructive review.

Attached is:

1) My response to George's 3 Phase Cascades Drilling Strategy (Oct 17, 1984 Memo), in the form of a flow diagram (10-26-84) and 2 page written summary
2) My initial Cascades Strategy Diagram (6-14-84)
3) My notes from John and my meeting with Pat, at which time he outlined his strategy for the Cascades.
4) Mike's Exploration Architecture for Basin & Range Geothermal.

My approach emphasizes: review of existing data; extensive geophysics across the structural grain; development of conceptual and drill targeting models; and <u>then</u> drilling. I assume backpack and helicopter deployed geophysics across very rough terrain — not along the roads. Santiam Pass troubles me — it is (NW) oblique; I don't understand what is controlling the low topography; and, I fear following the axis of an unrecognized structure that distorts the relationships we are trying to unravel. Bill Holman points out that it doesn't have Quaternary volcanics either.

My objective is geothermal reservoir discovery and development. George's is understanding the roots of a volcanic arc. They are related, complimentary, and fundamentally different.

Marty

[illegible]