OREGON GEOTHERMAL RESOURCE ASSESSMENT

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GEOTHERMAL SYSTEMS IN OREGON

The state of Oregon contains over 200 surface thermal manifestations of geothermal energy, including hot springs, fumaroles, mud pots, and warm water wells. Those with estimated minimum subsurface reservoir temperatures above 90°C (194°F) are shown in Figure 1. Most of these hotter systems are within the Basin and Range and Cascade Range Provinces; several are also in the Blue Mountain Province in the northeastern corner of the state. To date, the U.S. Geological Survey (USGS) has established 13 known geothermal resource areas (KGRA) in Oregon, 5 of which are in the Cascades and the remaining 8 in the Basin and Range.

In early 1976, the senior management of Portland General Electric Company (PGE) directed that a comprehensive study be undertaken to evaluate the geothermal energy potential of these areas, and of Oregon in general. The ensuing study involved nearly a man-year's effort by three principal investigators. Our initial efforts in resource appraisal involved a detailed compilation, review, and assessment of all available published and unpublished geological, geophysical, geochemical, and hydrological data on each of these 13 KGRAs and on the area around Glass Buttes and LaGrande, as shown in Figure 2. An additional area in the southern Washington Cascades, the Indian Heaven KGRA, was also included because of its proximity to PGE's Northwestern Oregon service territory. A large portion of this initial effort was devoted to development of an in-house understanding of the geologic occurrence and nature of geothermal systems in Oregon to provide a foundation from which to develop and evaluate possible future Company resource positions. Primary data sources included published journals, federal and state bulletins, and geologic maps, with augmentation by unpublished thesis, USGS open-file reports, and personal communication with other geothermal investigators. Where suitable, relevant data was plotted on 1:250,000 AMS sheets, thus enabling discernment of spatial and temporal patterns.

During the course of this literature investigation, it became evident that geothermal systems in Oregon and southern Washington might be subdivided into four generalized types of occurrence based upon their geological and hydrological setting. These are identified in Figure 3 as the Basin and Range resource type with the Brothers Fault Zone sub-type, and the High Cascade resource type with the Western Cascade sub-type. Each of these resource types differs somewhat with respect to geologic age, rock lithologies, age and style of deformation, age and type(s) of volcanism, and availability of subsurface water. These differences will probably ultimately be reflected in the physical nature and producibility of individual geothermal reservoir systems.

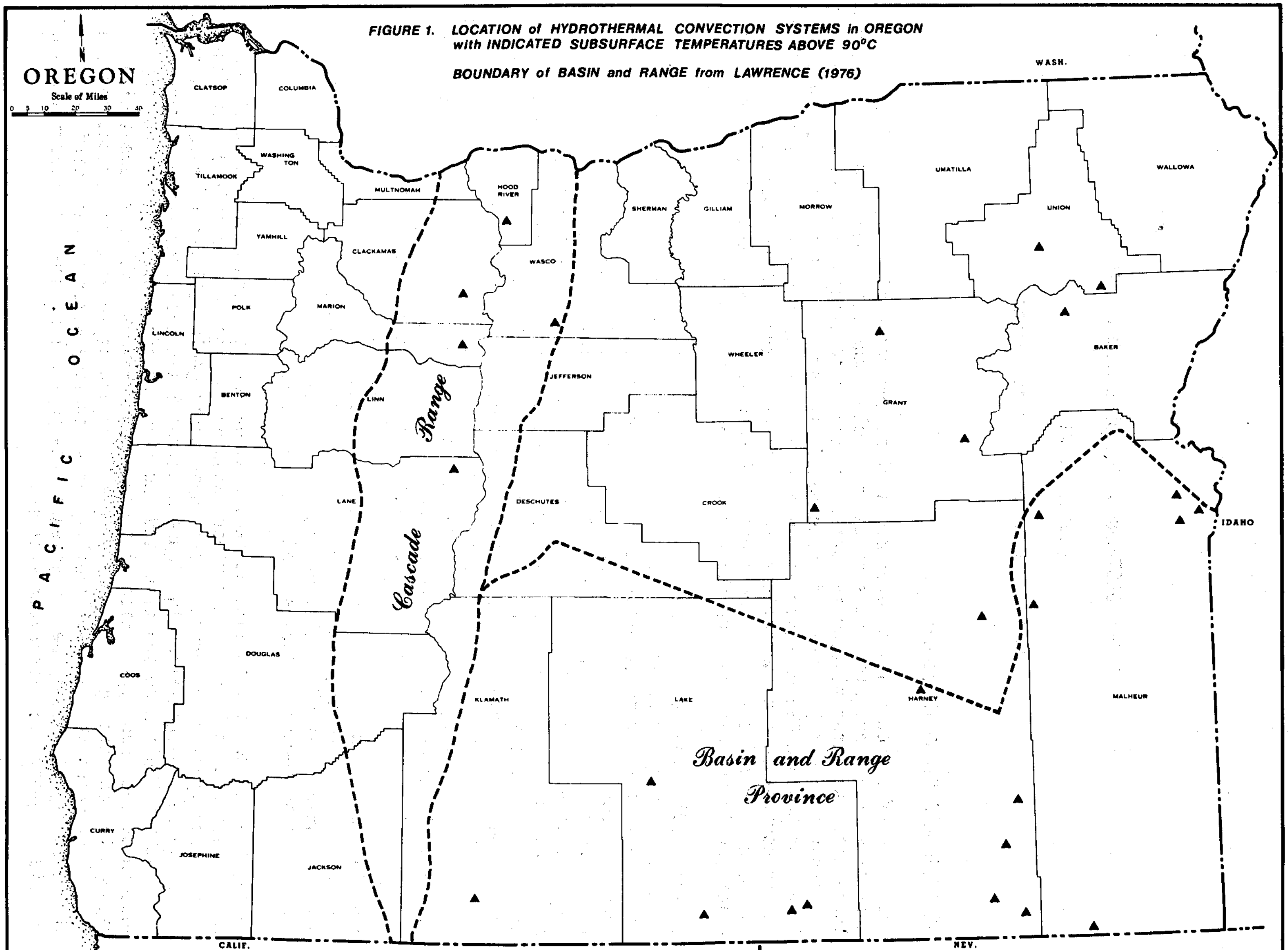

FIGURE 1. LOCATION of HYDROTHERMAL CONVECTION SYSTEMS in OREGON with INDICATED SUBSURFACE TEMPERATURES ABOVE 90°C

BOUNDARY of BASIN and RANGE from LAWRENCE (1976)

SOURCE: U S GEOLOGICAL SURVEY CIRCULAR 726 (1975)

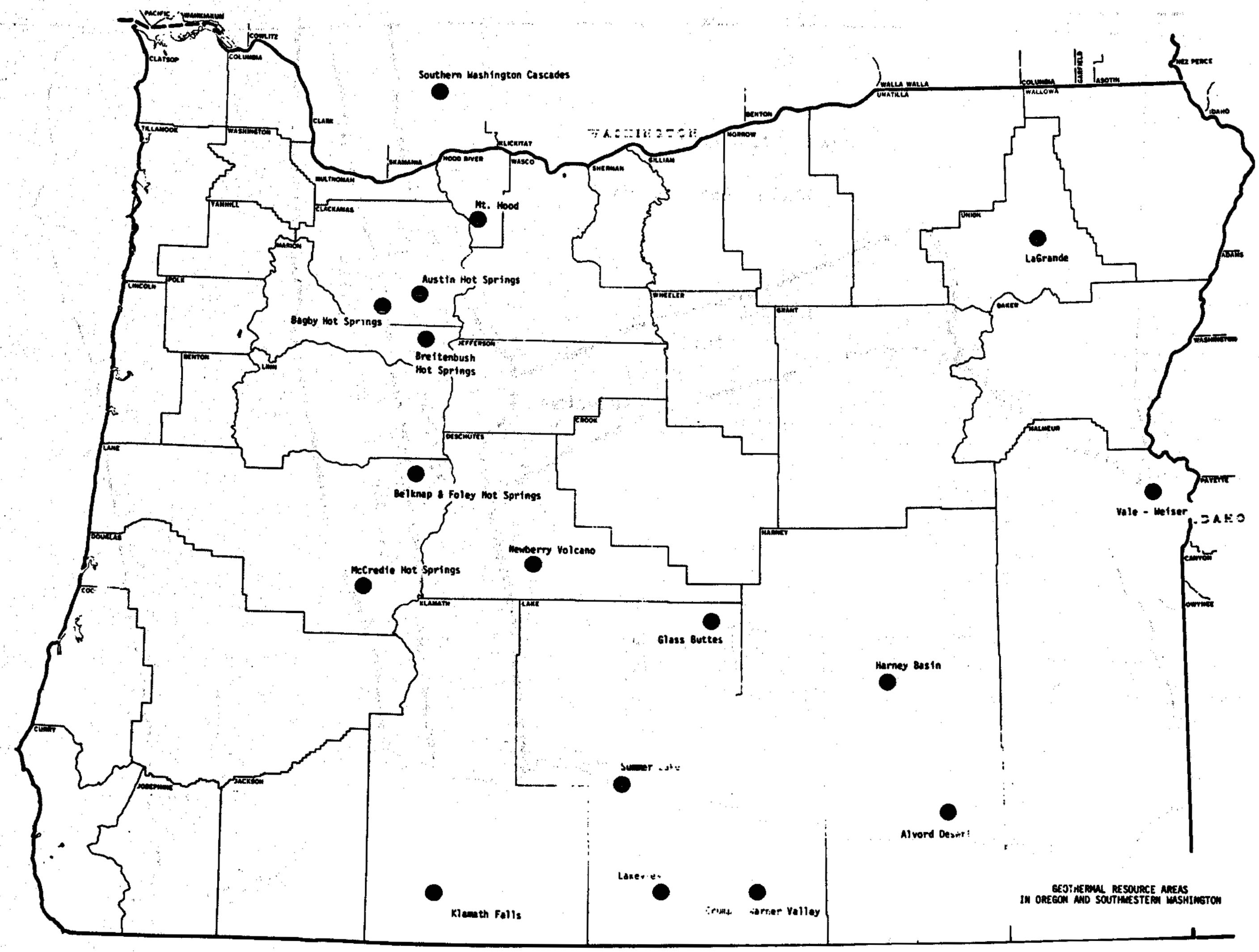

Figure 2. Geothermal Resource Areas in Oregon and Southwestern Washington

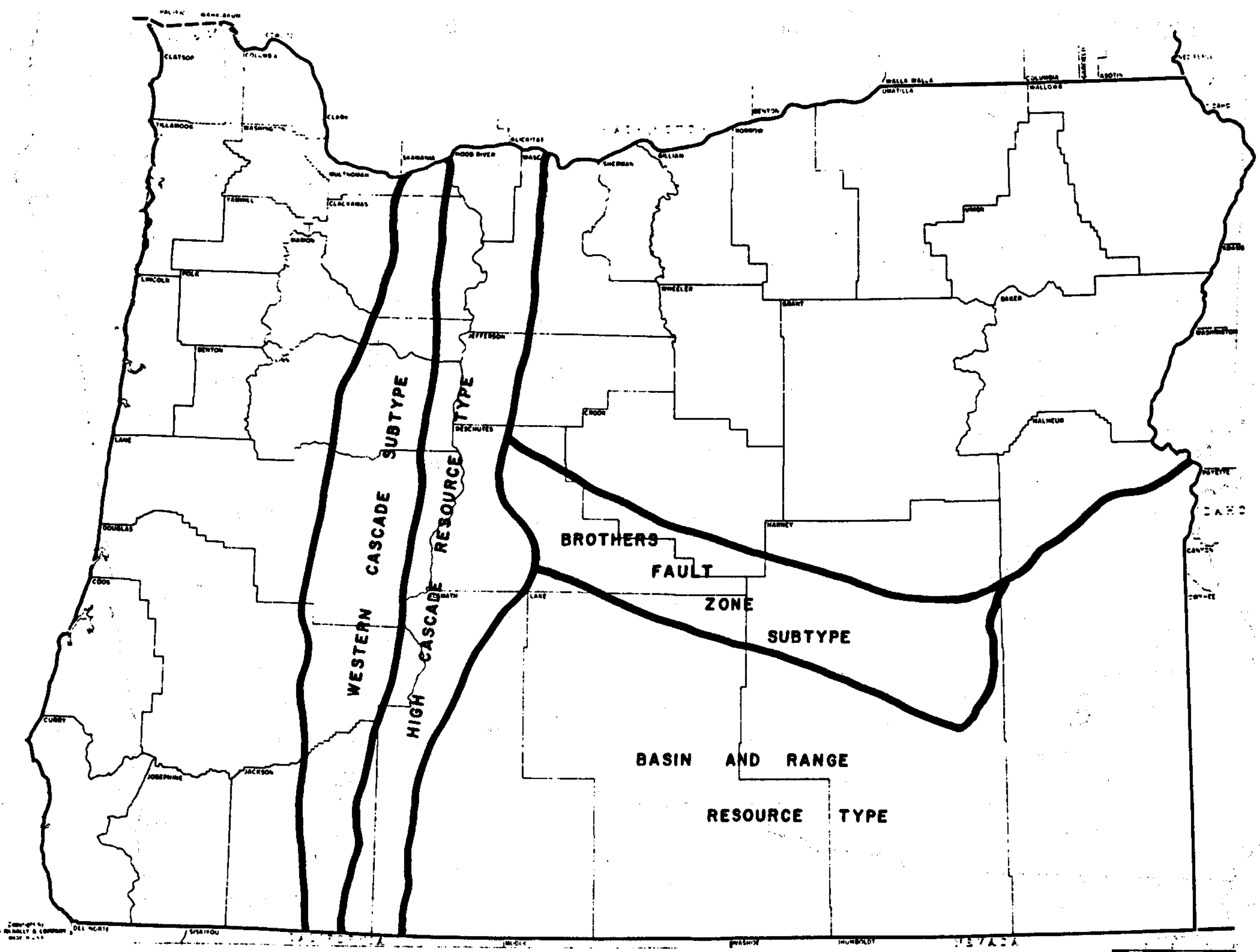

Figure 3. Generalized Geothermal Resource Types in Oregon

In order to perform a preliminary assessment of the relative merits of individual resource areas in Oregon and southwestern Washington, a list of 25 geological, geophysical, and geochemical indicators of potential geothermal systems was developed. This group of indicator criteria, which is shown in Table 1, was developed through review of exploration case histories for producing geothermal fields. Of these criteria, several occurred at most of the producing reservoirs and are, therefore, considered key indicators. These include:

- Presence of hot springs with discharge temperatures greater than 70°C (158°F) and geochemically-determined subsurface temperatures greater than 150°C (302°F)
- Presence of geysers, fumaroles, or mud pots
- Rhyolite and dacite domes and flows less than 2 million years old
- At or near the intersection of two or more major structural trends
- Hydrothermal alteration and extractable quantities of mercury
- Holocene volcanism

The presence of other criteria in conjunction with these key indicators enhances the possibility of locating a potentially commercial geothermal resource by deep drilling. It was our contention during this investigation that regional screening utilizing these 25 unweighted indicator criteria would greatly facilitate locating target areas for application of various geoscience exploration techniques, and possible result in the delineation of property for which PGE might wish to secure a lease position.

In performing the regional screening utilizing these 25 indicator criteria, and subsequently manipulating indicators experimentally within a given resource type, consistent groupings of areas became apparent. Those areas displaying the greatest number of favorable indicators were assigned highest priority for possible additional detailed investigation to assess their geothermal potential. Whereas this rather simplistic screening methodology contains obvious inherent biases, it was a relatively cost-effective way for an electric utility to attain current knowledge of the occurrence and possible controls of geothermal resources in Oregon and begin establishing the relative potential of each prospect area. This type of analysis is of necessity dynamic, as the data base is continually expanded and refined, and obviously the relative priorities for future investigation might change accordingly.

PGE GEOTHERMAL PROPERTY POSITIONS

As an outgrowth of the literature review and assessment work, and through independent discussions with a geologic consultant to PGE, Dr. Paul E. Hammond of Portland State University, four prospect areas in Oregon were identified for consideration as possible Company resource positions. Subsequently, in November 1976, PGE filed noncompetitive geothermal lease applications on two of these prospects with the Bureau of Land Management. Both are within national forest lands in the High Cascade Range - one totaling approximately 87,008 sq m (21,500 acres) is on the east flank of Mt. Hood, and the second comprises roughly 115,336 sq m (28,500 acres) immediately east of and adjacent to the Three Sisters in the vicinity of Three Creek and Melvin Buttes. Both of these two major andesitic stratovolcano complexes have been active during the Pleistocene and exhibit other characteristics which make them favorable geothermal exploration targets. In addition, both are within areas designated as "suitable" for the siting of geothermal power plants by the Oregon Energy Facilities Siting Council, which has the statutory authority to regulate siting and construction of all thermal power plants with installed capacities of greater than 25,000 kW in the State. Prospective sources for power plant cooling water makeup also exist in both areas.

PGE considers these two land parcels as research areas in which to test some of our ideas regarding the nature and occurrence of geothermal systems in the Cascades. As yet, detailed exploration programs have not been developed to evaluate these specific properties. Our ultimate strategy for assessment of these lands will, in part, be dictated by the results of a cost-benefit/risk analysis presently nearing completion, the results of which will also provide the basis for determining if, and to what extent, a regulated electric utility should become involved in a high risk geothermal exploration venture.

Nevertheless, PGE is in the midst of a geologic mapping program of the Three Sisters area, which is being undertaken by Dr. Edward M. Taylor of Oregon State University, who is employed by the Company under a summer faculty internship program. This mapping will provide geologic control for the eventual location and drilling of temperature gradient and heat flow holes, as well as enhance the interpretation of geophysical data from surveys which might be conducted at a later date. The Company is presently in a holding pattern with respect to evaluation of our Mt. Hood property position pending completion of a recently initiated three-year investigation of the Mt. Hood volcano being performed jointly by ERDA, the USGS, U.S. Forest Service, and the Oregon Department of Geology and Mineral Industries. The outcome of this investigation will not only afford a test of Mt. Hood's geothermal potential, but also serves as an exploration case history from which to design programs to evaluate the potential of other Cascade Range volcanoes.

OREGON GEOTHERMAL RESOURCE QUANTIFICATION

During presentation of the results of our Summer '76 program to PGE's senior management, we were instructed to develop a detailed rational quantification of Oregon's geothermal potential to serve as a planning guide from which management could base an initial decision regarding the potential long-range contribution of geothermal energy to the Company's generation resource inventory. Previous estimates of Oregon's geothermal potential for electric power generation range from the USGS preliminary estimate of 400 MWe-centuries in Circular 726, "Assessment of Geothermal Resources of the United States - 1976," to the 6500 MWe-centuries from dry steam resources alone, as proposed by one Oregon geothermal explorer.

To assist in the actual task of subjectively quantifying Oregon's geothermal potential, and to provide overall technical guidance to the future direction of PGE's geothermal program, the Company retained a four-man panel of geothermal consultants. This panel is composed of highly qualified and respected experts from the geothermal community: Dr. Gunnar Bodvarsson, Dr. James B. Koenig, Dr. H. Tsvi Meidav, and Dr. L. Trowbridge Grose.

The methodology we are considering for implementation in our resource quantification effort is a refined version of the USGS approach for assessing hydrothermal convection and igneous-related systems, as presented in Circular 726. Many of the generic assumptions developed by the USGS have been modified to portray better our present understanding of Oregon's geologic and hydrologic environment. In addition, an expanded geophysical and geochemical data base over that available to the USGS two years ago, and the recent availability of both published and unpublished new radiometric age dates, should enable upward refinement of the results tabulated in Circular 726.

As part of this quantification effort, hypothetical models of geothermal reservoir systems in the Basin and Range Province and Cascade Range will be developed by the panel, based upon experiences gained in similar geologic environments and upon case histories of producing geothermal fields in analogous settings. These models will be used to put physical constraints on individual reservoir systems for the quantification task, and will also aid in the design of exploration strategies to evaluate geothermal occurrences in these two resource types.

Initially, each panel member's input to quantification model development is being obtained through individual responses to technical questionnaires designed to allow development of concepts regarding the occurrence, probable physical and chemical nature, and geologic controls of geothermal systems in Oregon. As each member's response is of necessity subjective and based upon his own experience in geothermal prospecting, we presently envision utilization of the Delphi technique to attain the unanimity eventually required in model development and subsequently in the quantification task.

We realize that resource quantification is an inexact process wrought with many inherent uncertainties - not the least of which is a poor understanding of geothermal systems in general and an inadequate data base specifically. Nevertheless, we and our panel of consultants agree that a great deal can be learned in going through the quantification procedure and that the validity of any resource estimate is not in the final answer itself but in the detailed and carefully conceived methodology employed in deriving the estimate. It is anticipated that our initial subjective quantification will be refined as additional data becomes available and our models are tested through exploration. Ultimately, this process will be replaced by objective and measured reservoir data as individual geothermal systems are discovered and developed.

Hopefully, a utility effort, such as PGE's, in Oregon geothermal resource development will encourage others in the industry to undertake more active programs in this state. Furthermore, we are hopeful that such a combined and cooperative effort will lead to the delineation and testing of a medium-temperature, low-salinity hydrothermal resource on a time scale that will enable construction of a demonstration unit by the mid-1980s. In the long run, if costs are competitive with other generation alternatives and if the resource is available in commercial quantities in Oregon, PGE can envision adding geothermal capacity to our resource mix; perhaps by the early 1990s.

Table 1

REGIONAL GEOTHERMAL INDICATOR CRITERIA

- Hot spring or well with surface discharge temperature of >70°C (158°F)
- Estimated reservoir temperature of >150°C (302°F)
- Hot spring depositing quartz, chalcedony or siliceous sinter
- Hydrothermal alteration
- Hot spring with flow >150 l/min and chloride content >500 ppm
- Hot spring with lithium content >1.0 ppm and/or boron >10 ppm
- Mercury production >25 flasks (quantity is arbitrary)
- Presence of geysers, fumaroles, or mud pots
- Hot springs and/or warm wells covering >2.59 sq km (1 sq mi) and/or along a 8.05-km (5-mi) linear zone
- Rhyolite or dacite domes and flows
- Rhyolite or dacite domes and flows <2 million years old
- Collapsed caldera of late Tertiary or Quaternary age
- Holocene volcanic activity
- Proximity to regional tectonic feature
- At or near offset of a tear fault
- At or near intersection of two or more major structural trends
- Temperature gradient >80°C/km and/or heat flow >2.5μcal/(cm^2 s)
- Gravity anomalies (high or low)
- Low magnetic values within volcanics
- Magnetic lineament >8.05 km (5 mi) in length
- Microseismic or ground noise anomalies
- Unusual seismic activity
- Electrical resistivity anomalies
- Quaternary basaltic field of >64.8 sq km (25 sq mi) area
- Faults with cumulative displacements of greater than 1.5 km (5000 ft) or individual faults with greater than 305 m (1000 ft) of displacement
- Presence of near-surface thermal insulation layers