GEOTHERMAL

The following are Air Force bases at which we have had active contact with DOD personnel:

BASE	BACKGROUND	CURRENT STATUS
Ascension Island Patrick Air Force Base Systems Command Melbourne, FL Geothermal Potential: Excellent	Phase I work consisting of a preliminary geology study, a baseline system design, and an economic analysis have been completed using Air Force funding ($80K). The Air Force has funded Phase II which includes additional geophysical surveys, slim hole drilling, and a reevaluation of project economics ($650K). If approved, Phase III will consist of the drilling of a deep production well ($3.5M). The DOE will manage drilling of the well for the Air Force.	ESL/UURI personnel returned from Ascension Island on March 12 after completing a detailed aeromagnetic survey and a preliminary self potential survey. In addition, they performed an evaluation of the possibility of using an electrical resistivity survey to measure the resistivity of rocks at depth and found that this method can be used on Ascension Island. Current plans are to return to the Island and perform this survey as part of the Phase II task. The next work will involve an analysis of the data and an update of the conceptual models of the system at Ascension. However, the model cannot be updated completely until small diameter thermal gradient holes have been drilled and these holes logged by geological, geophysical, and geochemical methods. Permission to drill these holes has yet to be obtained, and there will be a month-to-month delay in the schedule until this permission has been granted.

BASE	BACKGROUND	CURRENT STATUS
Ascension Island (cont'd)		In addition, the Air Force requested that DOE investigate the feasibility of increasing the power generating capability to 4 MW from the previous 2 MW. A design concept and economic analysis was performed so the Air Force can use the information in their FY-86 budget request.
Ellsworth AFB SAC Rapid City, SD Geothermal Potential: Good	Ellsworth AFB has a geothermal potential similar to Minot AFB, and it is in the same command. If the Air Force decides to pursue the Minot AFB project and it is successful, Ellsworth AFB will likely follow.	No follow-up will be made until the Minot AFB heat pump study is completed.
Hill AFB Logistics Air Command Ogden, UT Geothermal Potential: Low	A geothermal exploratory well was drilled at Hill AFB in 1979. The well was dry and non-donducive of a resource. A groundwater heat pump has a fair probability of being economical at Hill. No further work will be done on this base until the heat pump study is completed.	No change.

BASE	BACKGROUND	CURRENT STATUS
Holloman AFB TAC Alamogordo, NM Geothermal Potential: Good	Holloman AFB has a good geothermal potential. A study on the economics of a geo-space and domestic hot water heating system was completed and mailed to the base energy officer. The discounted payback period was 9.4 years, which reflects relatively high costs projected for resource exploration and recovery. Holloman is in the same command as Mountain Home AFB (TAC). There currently is a proposal into the TAC on Mt. Home and it has not been approved. It has a payback slightly better than Holloman, and the probability of finding a resource is considered to be better. Therefore, no additional action will be taken on Holloman unless they request additional information.	No change in status.
Kelley AFB LAC San Antonio, TX Geothermal Potential: Good	Kelley AFB is adjacent to Lackland AFB where an exploratory well will be drilled. Base personnel are currently waiting for results of the Lackland drilling prior to proceeding with a geothermal development. There have been some indications at the command level that there is an interest in proceeding without waiting for the Lackland results.	No change.
Kingsley Field TAC Kingsley, OR Geothermal Potential: Good	Kingsley Field, located on the south side of Klamath Falls, is currently a reserve base. However, TAC is considering a major change of mission by the installation of long range radar. The field is near a good direct heat geothermal resource. If a major change in the base is planned, it may be an ideal time to install a geothermal system.	H. R. Hilker discussed Air Force plans for Kingsley Field when he met with TAC HQ personnel during March. Energy personnel at Kingsley Field will be contacted to determine if there is an interest in pursuing geothermal development. A report from the Oregon state team leader is attached which verifies the excellent potential for geothermal around the base.

BASE	BACKGROUND	CURRENT STATUS
Kingsley Field (cont'd)	Faulting exists in the area and with proper investigation, a resource should be found with about 120°F water. Water with temperatures of 160°F exist about a mile north of the base. Air National Guard is increasing its activity and moving in perhaps 250 to 300 people. A previous evaluation with three dry exploratory wells was completed several years ago when the facility was under the Air Defense Command. An evaluation of this study will be made.	

BASE	BACKGROUND	CURRENT STATUS
Lackland AFB ATC San Antonio, TX Geothermal Potential: Excellent	The Air Force has accepted a Department of Energy proposal to drill an exploratory deep well at Lackland AFB. The total project cost is $620K. The project will be developed in two phases, with a USAF decision point for withdrawal following Phase I in the event that early indicators from literature searches are not encouraging. Phase I will consist of an environmental assessment, compilation, integration and interpretation of available geologic and hydrologic data to select the well location and design of the well. Additionally, the permitting process will be initiated. During Phase II, the permitting process will be completed, subcontractors will be solicited for well drilling and logging, the well will be drilled and logged, test equipment will be procured and the well will be tested. If the well is not successful, the well will be capped according to local regulations and the site restored to original grade.	Geologic work was initiated. Well logs, maps and drill cuttings were examined. The cuttings indicate that the target zone is coarse sand to pebble aggregate, and is totally uncemented, so the permeability should be high. Disposal of test effluent to the sanitary sewer appears unfeasible because of capacity limitations.
Lajes AFB MAC North Atlantic Geothermal Potential: Excellent	Lajes appears to have the best geothermal potential of all Air Force bases. It is on an island in the Azores which has hot springs and which has had volcanic activity within the last two hundred years. There is a geothermal power plant on an adjacent Azore Island. The Air Force is interested in proceeding with the project but the current agreement with Portugal has not been extended by Congress and the Air Force will most likely wait until this problem is resolved. They will then have to negotiate an agreement with Portugal on resource utilization.	No change in status since T. Lawford made a presentation to HQ personnel at Scott AFB.

BASE	BACKGROUND	CURRENT STATUS
Lajes AFB (cont'd)	After these are accomplished, they have expressed an intent to request Department of Energy support in implementing a geothermal program at the base.	
Minot AFB SAC Minot, ND Geothermal Potential: Good	Under the Federal Building Program we conducted a study to develop a heating system at Minot AFB. Headquarters SAC decided not to pursue the project as the economics were marginal and they thought our estimated costs for portions of the project would be higher than we predicted. In doing the preliminary study we did not visit the base and we could not properly address the items they questioned. Because of funding limits we have not done any additional work on this project. The design we proposed utilized heat pumps in conjunction with a very low temperature resource. We believe that with additional design work we could convince the Air Force to proceed with this project. If this project were to proceed, it would open the way for a number of other Air Force base projects and would be a real boost for geothermal utilization. We are conducting an in-house study of a heat pump application which could improve the Minot economics. We will not recontact Minot until the heat pump study is completed.	The heat pump study has been delayed because of other priorities.
Mountain Home AFB TAC Mountain Home, ID Geothermal Potential: Good	Mountain Home has excellent potential for a direct heating system. A preliminary economic analysis has been prepared and a proposal submitted to the base. Mountain Home AFB has submitted the EG&G proposal for Phase I work on a geothermal space heating system to TAC HQ in Arlington, VA. The project has a strong supporter at TAC HQ and he is trying to get the proposal funded in FY-83 despite marginal economics.	It was learned during visit of H. R. Hilker to TAC HQ on 3-23-83 that TAC HQ is requesting a proposal from Mt. Home for the $83K Phase 1 and $400K for exploratory drilling. Also MCP budget request for FY-86 will include $3M.

BASE	BACKGROUND	CURRENT STATUS
Mountain Home AFB (cont'd)	Mountain Home AFB has requested EG&G advise them on the feasibility of generating electric power on the resource thought to exist on the gunnery range south of the base. They would like to go into a third party contract similar to the Navy approach at the COSO geothermal site at China Lake. UURI is investigating the resource potential. If it is of potential electric quality, a proposal will be prepared.	UURI has determined that there is little probability of an electric quality resource at the gunnery range.
Norton AFB MAC San Bernardino, CA Geothermal Potential: Good	Norton AFB was evaluated as a part of the Federal Building Program. It is in the same command as Lajes and the command prefers to pursue Lajes first. If the Lajes project is successful, there is a good chance that Norton AFB personnel will also become enthusiastic for a project. We agree that Lajes is the best project and it should be pursued first. We have made contact with Norton and they are interested. UURI's latest resource estimate makes Norton questionable. However, we will take another look at it.	No change in status.
Vandenberg AFB SAC Lompoc, CA Geothermal Potential: Good	A preliminary study was completed on the geothermal potential at Vandenberg. The economics are marginal and base personnel showed little enthusiasm for geothermal. No additional work is planned on this project.	No change in status.
Williams AFB ATC Chandler, AZ Geothermal Potential: Good	The Air Force had issued an RFP for a commercial development. We were on the review team and recommended against the one proposal received. Dick Steed, the Air Force project manager (and also the manager of the Lackland project) is still interested in proceeding with a geothermal development at Williams AFB. It is our opinion that if we had funding to study this project,	No change in status.

BASE	BACKGROUND	CURRENT STATUS
Williams AFB (cont'd)	we could develop a potentially economical geothermal concept and the Air Force would proceed with the recommended development.	

BASE

The following are bases with good potential but we have not made contact with DOD personnel.

Luke AFB
Indian Springs AFB
Nellis AFB
Davis Monthan
March AFB
Keflavik
Sandia AFB

The following bases have some potential but we have not made contact with DOD personnel.

Army & Air Force Exchange - Dallas, TX
Clark AFB - Phillippines
Logistics Command - San Antonio, TX
Kirtland AFB - Albuq., NM
Carswell AFB - Fort Worth, TX
Fairchild AFB - Spokane, WA
Francis E. Warren - Cheyenne, WY
Griffins AFB - Rome, NY

Cy TWL
JHR
MRD

STATE OF OREGON
1859
VICTOR ATIYEH
GOVERNOR

Department of Energy

LABOR & INDUSTRIES BUILDING, ROOM 102, SALEM, OREGON 97310 PHONE 378-4040

March 17, 1983

Ben Lunis
EG&G Idaho, Inc.
P.O. Box 1625 WCB
Idaho Falls, ID 83415

Dear Ben:

At long last! Here's the data I promised you last month. The two areas are discussed separately below.

Umatilla Reservation

The Umatilla Indian Reservation lies within the Oregon part of the Walla Walla Basin which is a structural depression located in the Columbia Plateau physiographic province of eastern Oregon and Washington. That part of the plateau located in Oregon is known as the Deschutes-Umatilla Plateau. The basin is bordered on all sides by anticlines. To the east is the northeast trending Blue Mountains Anticline, to the south the west-northwest trending Horse Heaven Anticline, to the west the north-south trending Divide Anticline, and to the north in Washington is a low east-west trending arch.

The Columbia Plateau is underlain by a thick sequence of Miocene flood basalts, the Columbia River Group. In the Walla Walla Basin, the basalts are exposed only in the bottoms of streams flowing into the basin, and on the flanks of the anticlines bordering the basin. Within the basin the basalts are covered by a series of unconsolidated Pleistocene and Helocene deposits which are as much as 650 feet (198 m) in thickness. The deposits include graves, clays, loess, silts, slitstones, glacio-fluviatile deposits, and alluvium.

There are only scattered luke-warm springs (about 20°C) in the Walla Walla Basin. Early interest in the area was generated by rumors of warm irrigation wells, some of which were artesian at temperatures in excess of 38°C, though most fall into the range of 15 to 27°C. The warmest wells all turned out to be located in the center of the basin near the town of Touchet, in Washington.

Assessment effort in the region has been quite limited. Temperature gradients have been measured in only seven open water wells in Oregon, though a larger data set exists for the Washington side of the basin. No well sampling has been done for geothermal assessment, but limited geochemical data is available from groundwater studies which have included the Walla Walla Basin.m Silica geothermometers indicate minimum reservoir temperatures in the range of 100° to 120°C for some of the warmer wells in the area.

Based on the limited temperature gradient data available, it appears that the heat flow averages about 55 mWm^{-2} in the Walla Walla Basin. Typical gradients are 35° Ckm^{-1} in he basalts and 50°Ckm^{-1} in the lower thermal conductivity sediments overlying the basalts.

According to groundwater studies, there are several major sets of aquifers in the area. The shallowest is associated with older Pleistocene gravels. The water from wells penetrating these aquifers is typically cold and unconfined. The second is associated with flow contacts in the Columbia River Basalt. Waters from these aquifers are typically warm and artesian, with the wells commonly producing several thousand gallans per minute.

There is a low-temperature resource in the Walla Walla Basin adequate for space heating and other lower temperature direct-use applications. The high temperatures results from a combination of the somewhat high regional heat flow (55 mWm^{-2}) and the insulating cap of low thermal conductivity unconsolidated sediments. Where temperature in excess of 38°C occur, as in the Touchet area of Washington, it is probable that the fluids are derived from convection systems associated with mapped normal faults.

Given the nature of the Columbia River Basalts in the Oregon portion of the Columbia Plateau, that adequate quantities of warm fluids can be obtained at any specific site with the temperature obtained in a specific well dependent primarily upon the depth drilled. Therefore, future efforts should be directed primarily toward site specific engineering studies, to determine if the resource is adequate to supply the expected load. In certain areas detailed geologic mapping and geophysical studies will be useful for locating faults. Convective systems associated with faults would provide higher temperatures that normally expected at a given depth.

According to the Portland office of the Bureau of Indian Affairs the population of the Reservation is scattered with no central towns. Any uses for the geothermal fluid would probably be limited to agricultural or individual space heating uses. Study of the area has been limited. Therefore, I would suggest a modest study be funded through George Priest's group at DOGAMI to allow for some probing, sampling and further model refinement.

Kingsley Field

Kingsley Field is located approximately three miles south of the Klamath Falls city center. Geologically, the area is located within the Klamath Graben, a down-faulted valley in the transition zone between the Basin-Range and Cascade Mountains geomorphic provinces. The north and south end so the graben terminate at Mt. Mazama (Crater Lake) and Medicine Lake Highlands respectively, both large silicic volcanic centers. A more detailed evaluation of the geology and specific geothermal character of the area is contained in the GeothermEx report included with this report.

I feel that a well drilled to 2,000 to 3,000 feet would provide enough hot water to heat the entire Kingsley Field facility. This is based upon results obtained in drilling at the Modoc Lumber Mill, review of available geologic literature and discussions with local water well drillers.

In addition, two wells were drilled at the airport to approximately 1,000 feet by the City of Klamath Falls two years ago. The results and purpose of these wells is unknown to me at this time. However, as soon as I hear back from the City I will pass the information on to you.

If you have any further questions, please call.

Sincerely,

Dave

David Brown
Geothermal Program Manager
Renewable Resources Division

DEB:cs
17071(D1,F1)

GeothermEx, Inc. 901 MENDOCINO AVE.
BERKELEY, CA. 94707

(415) 527-9876

EVALUATION OF THE GEOTHERMAL POTENTIAL
OF THE
MODOC LUMBER COMPANY PROPERTIES
AND
POTENTIAL WELL SITE SELECTION
KLAMATH FALLS, OREGON

for

MODOC LUMBER COMPANY, INC.

KLAMATH FALLS, OREGON

by

Murray C. Gardner

GeothermEx, Inc.
Berkeley, California

Feburary 1981

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BERKELEY, CA. 94707
(415) 527-9876

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(415) 527-9876

CONCLUSIONS

1. The probability is good that aquifers exist beneath the Modoc Lumber Company property capable of producing at least 500 gpm from depths between 1,000 to 2,000 feet.

2. The temperature gradients at the property, and consequently the depth at which temperatures will exceed 150°F, is uncertain. Well-temperature data recorded in the immediate vicinity of the property are limited to shallow depths. Both anomalously high and low gradients occur in wells to the west and northwest of the property. A significant thermal anomaly occurs northeastward in Klamath Falls and may extend beneath the property.Therefore, a risk exists in trying to obtain temperatures of 150°F or higher at depths of 1,000 to 2,000 feet.

3. Drilling on this property should be located in the northeastern part of the property, as close to the possible fault traces bordering Lake Ewauna as is practical, because there is association of thermal anomalies and faults.

4. Cost for a production hole, at $40/foot including casing and completion to 1,500 feet, would be $60,000. If pumps are needed to assist flow, cost will increase accordingly. A production well will probably need to be 12 inches in diameter.

GeothermEx, Inc. 901 MENDOCINO AVE.
BERKELEY, CA. 94707

(415) 527-9876

INTRODUCTION

GeothermEx, Inc. was authorized in January, 1981 to perform an evaluation of the geothermal potential of the Modoc Lumber Company properties bordering Lake Ewauna near Klamath Falls, Oregon (figure 1). The purpose of the evaluation was principally to analyze the potential of the properties to support process heat requirements for densification of plant waste materials to solid fuel pellets. This assignment was directed by Eliot Allen & Associates, principal consultants to Modoc Lumber Company, and ordered by Mr. Kent Schmidt of the Wood Energy Products program.

Location

Modoc Lumber Company properties are comprised of about 150 acres distributed principally around the shores of Lake Ewauna. There are 3 parcels. The first is comprised of 40 acres along the north and east shores of the Lake, and extending into Klamath Falls City. This is the area of principal interest. The other parcels are on the western shore of the Lake and are both more distant from proven geothermal resources and from areas of potential use. A pipeline with prohibitive costs would be required to move thermal fluids from the western parcels to the use area.

Preface

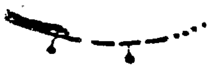
Modoc Lumber Co. has already accomplished several months of research and development activities for the solid fuel pellets program, with financial assistance from the U. S. Department of Energy. Geothermal energy may or may not be utilized, depending upon results of this feasibility study and exploration. The concept questioned was whether to (1) drill 1 one-thousand-five-hundred (1,500) foot depth hole, and attempt to produce about 500 to 1,000 gallons of water per minute (gpm) at temperatures of at least 150°F; (2) drill several five hundred (500) feet depth holes to examine temperature gradients; or (3) to abandon plans to use geothermal energy to supplement fossil energy.

Methods and Scope of Work

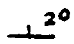
GeothermEx was requested to (a) review existing literature and documents about geology, hydrology, well temperatures and production; (b) visit the Modoc Lumber Company property to make a reconnaissance of

EXPLANATION OF GEOLOGIC SYMBOLS USED IN FIGURE 1.

Formation contact, dashed where approximately located



Fault, dashed where uncertain, dotted where projected ben alluvium. Ball shows direction of movement. Yellow i cates possible faults or fault zones interpreted from gravity and topography.



Attitude of bedding. Figure shows amount of dip

MAP UNITS

Ql	Alluvium, fluvial and lacustrine deposits
Ts / Tb	Ts = Pliocene lacustrine sedimentary rocks (claystone, siltstone, volcanic sandstone, basalt tuff, diatomit Tb = basalt flows, including some cinders and breccia around eruptive centers
Tob	Older basalt, including breccias, cinders, minor palagonit tuff and thin interflow sedimentary rock

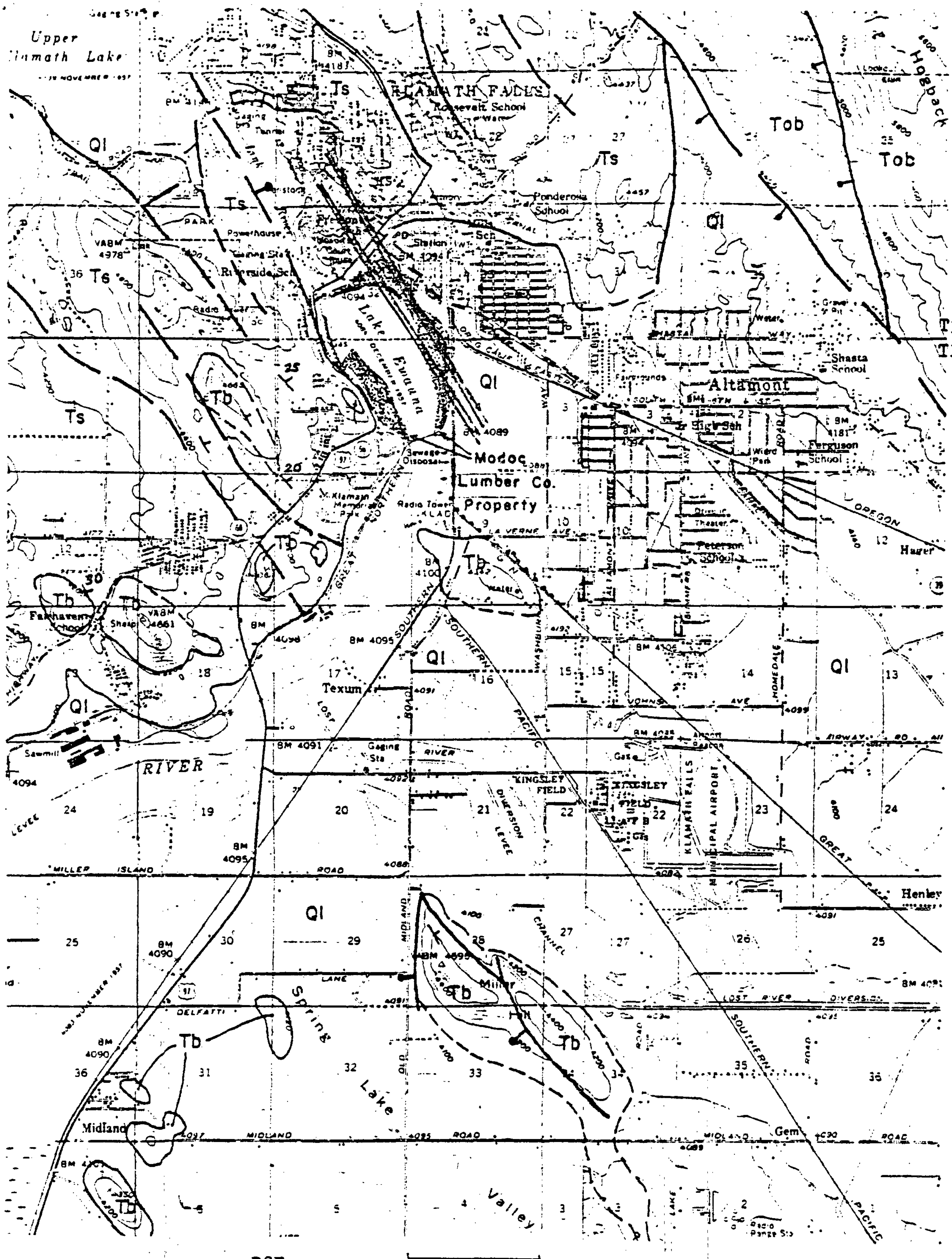


FIGURE 1. Reconnaissance geologic map of the Klamath Falls area.

the geology and hydrology; and (c) site a test hole or holes in the event it appeared valid to assume the existence of adequate geothermal fluids in the prospect area.

The principal result of the investigation was to be a concise report. This report fulfills the scope of work of the feasibility study. During the months of January and February, 1981, literature from public and private sources was collected and reviewed. A visit was made to Klamath Falls and discussions held with principals of Modoc Lumber Company and Eliot Allen & Associates, and a reconnaissance was made of the vicinity of the plant site. Data from wells was collected by Eliot Allen & Associates, as well as directly by GeothermEx from city and state agencies.

One of the proposed parts of the program was to use well information to construct a detailed geologic cross-section of the vicinity of the Modoc Lumber property. There is insufficient subsurface data to permit this undertaking with any significant detail. The structure of the area has been analyzed as far as possible to help site an exploration well.

GEOLOGIC SETTING

The area studied is at the southwestern margin of Klamath Falls City, and occupies the valley floor of the Klamath River between the Upper and Lower Klamath Lake depressions. This valley is a fault-bounded basin in the Klamath graben complex. This regional zone of en echelon fault-bounded ridges and valleys extends for at least 90 miles, from the Medicine Lake Highland volcanic center, California, on the south to the vicinity of Crater Lake, Oregon, on the north. From west to east the graben complex extends from Lake of the Woods, Oregon to the Sprague River Valley, Oregon. The Klamath Falls geothermal field is located along the east flank of the axial part of the Klamath graben.

Structure

The Klamath Basin is broken into numerous ridges (horsts) and valleys (grabens) by northwest-trending normal faults (figure 1). In the area northwest of the site the faults are closely coincident with steep topographic escarpments. At and southward of the site, the fault topography has been reduced by erosion and the landform has been covered by lacustrine and fluvial sediments. However, it is believed that the fault pattern persists beneath the younger deposits and that Miller Hill, as well as the small hill in Section 9, T. 39 S., R. 9 E., the low scarp along the west side of Lake Ewauna and the hills such as Ewauna Heights are fault-bounded. These faults are likely to be similar to those exposed in many uplifts in the Klamath Basin. Gravity data are insufficient to define them and the city culture obscures surface evidences. Exposures in many parts of the Klamath graben complex indicate that fault planes dip at 60° to 80°. It is assumed that any faults in the project area would follow this geometry.

Reconnaissance gravity data generally confirm a northwest structural grain of the area (Sammel, 1976). The data also indicate that important northeast-trending faults may be present. The property lies immediately southward along the trends of the projection of probable northwestward-trending faults north of Lake Ewauna, and near a possible northeastward trending structure indicated by the gravity data beneath the Klamath River.

Some of the faults in the region act as conduits for deep-circulating water, which rise surfaceward after heating at depth, and may spread laterally into shallow porous rock layers. The narrow, linear, northwest strike of the thermal anomalies at Klamath Falls, Klamath Hills, and Miller Hill support the close association of elevated groundwater temperatures with faulting.

Historical Geology and Stratigraphy

The oldest rocks which can be projected beneath the area with reasonable certainty are eastward-dipping Oligiocene and Micene volcanic and volcaniclastic sedimentary rocks exposed along the western side of the Cascade Range. The surface outcrop of these rocks closest to the project area occurs about 20 miles westward, in the Klamath River Canyon. The sequence of the rocks exposed there is estimated to be from 12,000 to 20,000 feet thick (Hammond, written communication, 1975).

Rocks belonging to this suite of Western Cascades rocks also appear to have been penetrated in the Thermal Power O'Connor Ranch No. 1 deep geothermal test well (40/9-35 ca), drilled in the Klamath Hills.

A variety of rock types are present in this assemblage, including abundant basalt flows; andesite flows, brecciated pyroclastics; and light colored, more acidic tuffs. Tuffaceous seidmentary rocks ranging from claystone to conglomerate are interbedded with the volcanic rocks. Little is known concerning the reservoir potential in these rocks, because no wells penetrate them. However, they are significant to geothermal prospecting, because deep tests drilled in search of high temperature fluids are likely to encounter them.

About 4 to 5 million years ago, following the deposition of the Western Cascades volcanic rocks, a period of widespread eruptions of basalts and basaltic andesites began. Extensive basalt flows were erupted to form tablelands and many of the older volcanic edifices of the High Cascades were built. Extensional faulting also began during this period.

Larger lakes formed in the areas of impeded drainage caused by volcanic and fault activity. The deposits of these lakes consist of diatomite, siltstone, claystone, basaltic tuff and sandstone, altered to palagonite. These deposits interfinger with lavas from contemporaneous eruptive centers.

Late in this period, faulting intensified, resulting in the development of the downdropped graben valleys and uplifted horst mountain ridges which characterize the present topography of the region. The lakes occupying the valleys continue to deposit clay, silt, tuff, peat and diatomite to the present time in many areas.

Volcanism also continued at a few localities such as Mount Mazama and Brown Mountain in the High Cascades and at the Modoc Lava Beds and Medicine Lake Highland until a few thousand years ago.

The history of this Pliocene to Holocene period is of special importance to geothermal prospecting. The lava flows of the early part of the period form the most productive shallow ground water reservoirs in the area. As such they also appear to produce most of the thermal water encountered in the region by this shallow drilling. The overlying lake sediments form impervious cap rocks over these reservoirs in the graben areas. The faults originating during this period provide fracture zones along which ground waters may circulate to great depths, be heated, rise convectively and spread out into the shallow aquifers. Calculations by McIntyre and Gardner (1980) and Sammel (1978) indicate a base reservoir temperature of about 265°F.

A number of localities in the Klamath graben complex contain thermal springs and wells. The most productive of these is in the City of Klamath Falls, where active development of shallow zones of water ranging from 135°F to more than 200°F has been going on for many years. Other areas with less-well-defined potential occur at Miller Hill, the north and west sides of Stuckel Mountain, Olene Gap, Eagle Point in Upper Klamath Lake, Yonna and Langell Valleys and along the west flank of Klamath Hills (Peterson and McIntyre, 1970).

The stratigraphic section illustrated in figure 1 and likely to be present beneath the site is summarized as follows.

Surface Deposits (Ql). These materials consist of silt, sand and clay in the flood plain of the Klamath River and flats around Lake Ewauna, where they may be as much as 100 feet thick. Elsewhere, they are less than 10 feet thick. Close to and surrounding basalt hills, the unit may include coarse basaltic scree. At the site, thick silt, sand and clay is likely to occur to below 100 feet depth.

Sedimentary rock (Ts) and Interbedded Basalt (Tb). Sediments (Ts) of the geologic section consists of lacustrine siltstone, claystone, palagonitic tuff, tuffaceous sandstone and diatomite in the areas east and south of the Klamath River. In one well (39/9-4aa), these materials are 1,040 feet thick. These rocks generally do not contain porous beds capable of large sustained water production. The upper part of the sedimentary section has been removed by erosion to the west of the river and the lower part, at least 250 feet thick, is interbedded with basalt flows, cinders and breccia. The origin of the volcanic rocks is apparently from small local eruptions. In the vicinity of the eruption vents, the rocks may be entirely basalt. Where basalt (Tb) predominates, it is not possible to separate this rock unit from the underlying formation (Tob), which is also composed of basalt flows. Sedimentary rocks are exposed north of the site, and their thickness is uncertain.

Older Basalt (Tob). The oldest rocks observed and mapped in this part of the basin consist of a sequence of basalt flows, flow breccias with thin interflow cinder zones, and tuff beds. The total rock unit may be more than 2,000 feet thick. The geologic sections mapped in Plum Hills and Hogback Mountain, northeast of Klamath Falls, are thought to be typical materials of this period. The boundary between (Tob) and (Tb) basalts is difficult to establish. The basalts of both units contain the important water-bearing zones.

HYDROLOGY

A model for ground water circulation in the Klamath Basin has been proposed by Illian (1970). Local, regional and intermediate ground water circulation regimes are illustrated in this model. The characteristics of the local systems are the short travel times and shallow depths of circulation between the recharge and discharge areas. Low water temperatures and low total dissolved solids concentrations are characteristic of this system.

By contrast, the regional system receives recharge from the Cascade Range. On the east side of the basin, infiltration through porous lava flows into fault zones takes place. This water may decend into the fault zones to depths greater than 10,000 feet and move laterally for long distances. The characteristics of water in this system are the long time and distance it remains in transit, its relatively high temperature and concentration of total dissolved solids. The conditions in this regional flow system appear to be adequate to account for the temperatures and compositions of waters found in the Klamath graben complex, without requiring an igneous heat source.

The intermediate flow system falls between the two already described. However, some waters appearing to belong to the intermediate system may actually be the result of mixing of local, shallow ground water with water rising from the regional source along faults.

No single continuous aquifer has been defined. The porous intervals are probably not continuous over long distances; this is true even for basalts. However, they may communicate with one another through fracture systems. Productivity from the basalt section varies considerably from well to well, depending on the porosity in individual zones and the number of such zones intercepted. From 20 to 2,000 gallons per minute have been produced in different wells. From the data available in the region, the probability is good that fluid production of more than 500 gpm can be obtained from a well drilled to depths of 1,000 to 2,000 feet, the depths at which temperatures of interest occur.

GeothermEx, Inc. 901 MENDOCINO AVE. BERKELEY, CA. 94707
(415) 527-9876

TEMPERATURE GRADIENTS

Several interrelated factors influence the temperature gradients encountered in wells. Among these are the mode of heat transfer, the varying thermal conductivities of different rock types, and the heat flow. Two types of heat transfer may occur. Of these, conductive heat flow takes place in non-permeable rocks. By contrast, convective transfer takes place by convective circulation of fluids through porous and permeable rocks. The thermal conductivities of various rock types are inherent properties of these rocks. Certain fine-grained, non-permeable rocks such as diatomite, clay and silt have low thermal conductivities, while crystalline rocks such as lavas have higher conductivities for any given heat flow. Heat flow itself is calculated, being the product of the observed average gradient in gradient holes, wells and mine shafts, multiplied by the measured thermal conductivity of the rock. Therefore, heat flow varies depending on whether the site of measurement is typical for an area or is influenced by local geological or hydrological conditions.

The essential factors which determine the success of geothermal drilling operations may be found at the site. The factors are: (1) presence of porous reservoir rocks capable of sustained production of fluids at the required rates, (2) occurrence of temperatures required for the projected uses, and (3) factors (1) and (2) at depths from which the fluids can be exploited economically.

The distribution of thermal gradient anomalies in the Klamath Falls areas is shown in figure 2. These are areas outlined from existing well data, in which gradients greater than 6.5°F per 100 feet occur and in which a temperature of 160°F or higher is likely to be encountered at a depth of 2,000 feet (Lund, 1978). The Modoc Lumber Company site is west of the present limits of production and use in the Klamath Falls City geothermal field. The site is northward from the northwestern end of a narrow anomaly extending through Sections 9 and 15. The site is within the area where it has been speculated (Lund, 1978) that there is a greater than average potential for hot-water from 120°F to 212°F at depths of 1,500 to 3,000 feet. Several shallow wells in the area provide temperature gradients and water flow at temperatures that support Lund's estimation.

To the northwest of the Klamath River, wells with gradients both above and below 6.5°F per 100 feet have been reported, but no pattern in their distribution is apparent. No well data are available from the east half of Section 5, or in parts of Section 4. Four wells are present in the west half of Section 5, ranging in depth from 185

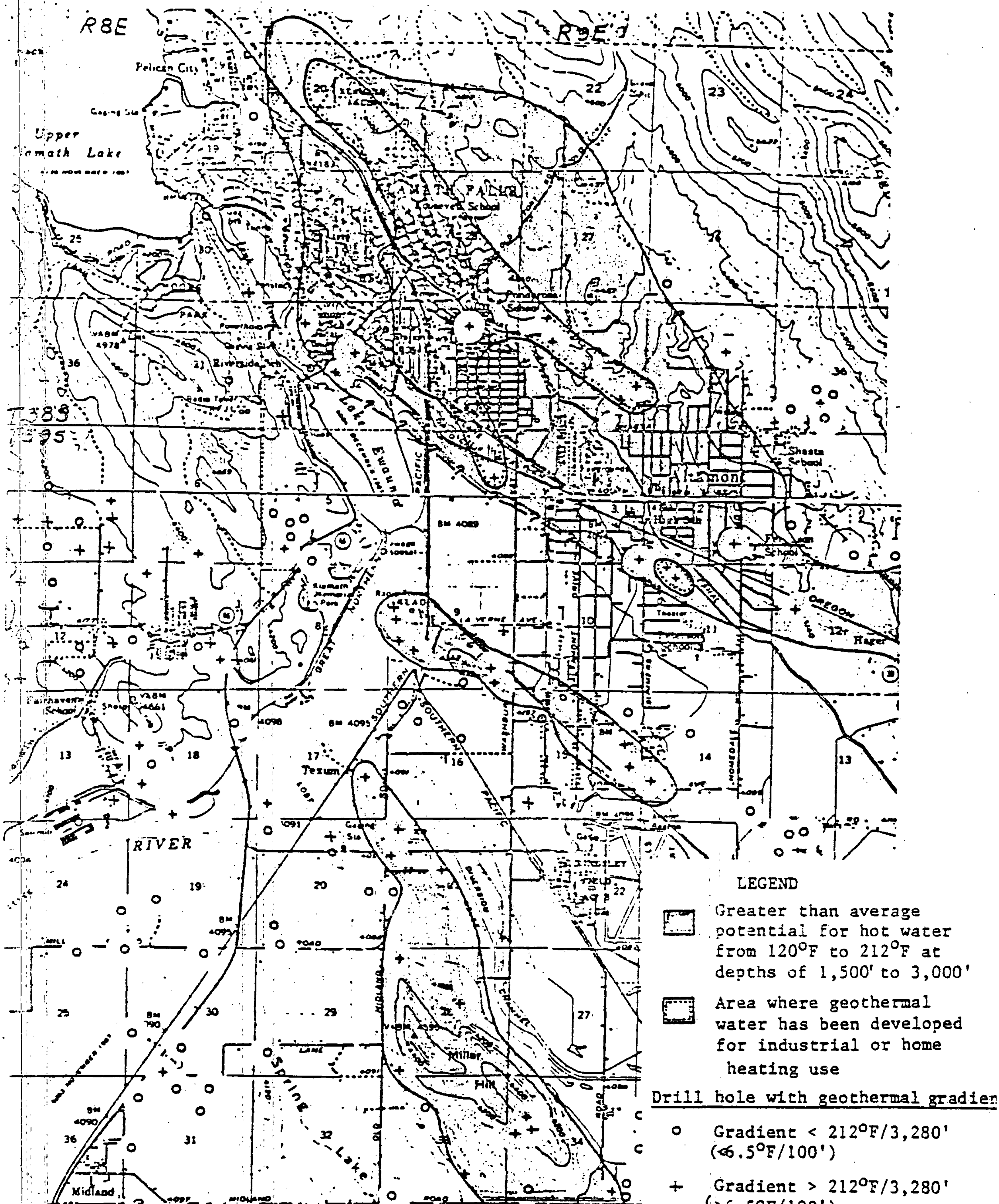


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FIGURE 2. Outline of thermal anomalies in the Klamath Falls area (modified from Lund, 1978)

to 308 feet. One hole (39/9-5cc), along a projection of the anomaly in Sections 9 and 15, recorded a temperature of 65°F at a depth of 247 feet, with an average gradient of 6.8°F per 100 feet. The gradients in the other three holes, which are also along the northwestern projection of the anomaly in Sections 9 and 15, range from 2.6°F to 3.8°F per 100 feet.

The Modoc Lumber Company property is generally outside of the areas studied and reported upon by Lund (1978). On most maps in Lund's report, the property is southwest of the termination of temperature gradient contour lines and other factual and interpretive guides.

Map No. 8 of Lund (1978), which shows artesian and pumped wells, does show an area with four thermal wells between 4th Street and Lake Ewauna which are used for heat pumps. The closest 2 are near Pine and Klamath Avenues.

There is little question that the maximum well temperatures fall off rapidly toward Lake Ewauna from the central part of the hot well area. Temperatures of 40°C (145°F) have been observed within 1,000 feet of the Modoc Lumber Company property.

Temperature information was obtained from public and private sources for several wells located within the vicinity of Modoc Lumber Company property. In nearly all cases, gradients calculated from the maximum temperatures of water in the wells were greater than 6°F/100 feet. This permits speculation that aquifer temperatures may be higher than 150°F in a hole drilled to 1,500 feet depth. Local well information includes:

1. Ganong - 323 Main Street
   Temperature - 64°F
   Static Water Level - 16 feet
   Total Depth - 155 feet

   This well increased about 14°F in 155 feet or about 9°F/100 feet. It could be projected to a temperature of 180°F at 1,400 feet depth, with the above-mentioned cautions.

   The well did intercept beds of basalt from 28 to 148 feet depth, according to the driller's logs.

2. Molatore - 626 South 7th Street
   Temperature - 74°F
   Static Water Level - 7 inches
   Total Depth - 378 feet

This well increased about 24°F in 378 feet or about 6-1/2°F/100 feet. It could be proejcted to a temperature of 130°F at 1,400 feet depth again with suitable cautions. The well bottomed in 13 feet of "black broken basalt." It is not certain whether the well entered an isothermal regime.

3. Molatore - 100 Main
   Temperature - 69°F
   Total Depth - 307 feet
   Static Water Level - 76 feet. Water encountered at 144 feet.

   This well increased about 19°F in 307 feet or about 6+°F/100 feet. This is approximately the same as No. 2, the "other" Molotore well. The well bottomed in 30 feet of basalt.

4. Consumer Heating/Klamath Heating Co. - 38-9-321(1)
   Temperature - 72°F
   Static Water Level - ?
   Total Depth - 263 feet

   The well increased about 22°F in 263 feet depth or about 8+°F/100 feet. This gradient would project to about 170°F at 1,400 feet. Lithologies were not found.

5. Oregon Water Corp. City Well #9 - 5th & Elm Streets
   Temperature - 75°F
   Static Water Level - ?
   Total Depth - 845 feet

   The well increased 25°F in 845 feet depth, for a gradient of about 3°F/100 feet. This is basically a cold water well. The well entered basalt aquifers at about 400 feet and is possibly isothermal below that depth. Basalts persist until about 733 feet, when stick shales occur.

An abandoned well at the entrance to the Modoc Lumber Company administrative headqaurters was opened, flowed and measured. The history and depth of the well are indefinite.

From these data it appears that a drill hole at the site would have a temperature gradient of more than 6°F per hundred feet and may intercept water between 150° and 200°F at depths between 1,000 and 2,000 feet. There are uncertainties and risks in this, reflecting the uncertainties of (a) temperature gradient at the site, and (b) depth to a thermal aquifer. For example, if a thermal aquifer were encountered at 800 feet, at a gradient of 6°F per hundred feet, temperature would be 98°F. If an aquifer were found at 1,500 feet, and the gradient were 6°F per hundred feet, the temperature would be 140°F.

The ideal situation would be one in which formations with low permeability are penetrated by a drill hole to depths of about 1,400 feet. The low permeability rocks--non-fractured siltstones, tuffaceous sediments and so forth--would permit the conductive temperature gradient to continue and in-crease. Then, below 1,400 feet depth, a high permeability unit such as fractured basalt would be required to provide adequate water flow or circulation around a heat exchanger. Whenever a high permeability unit is penetrated, it is expected that the temperature will become isothermal or nearly so; unless a succession of low and high permeability units were penetrated, this would lead to step-ups in temperature. The records from the majority of Klamath Falls hot wells indicate that a single cell is to be expected once the permeable formation is reached. Using an average annual temperature of 50°F for a base, if there were a minimum temperature gradient of 7°F/100 feet, a temperature of 150°F would occur at 1,400 feet depth. Of course, there may be a sudden and significant increase when a hot aquifer is encountered, but this event is entirely fortuitous and speculative now.

DRILLING SITE SELECTION

On figure 3, areas are recommended for the geothermal well site. A final location would depend upon (a) site accessibility and (b) environmental or land-use factors. These could only be resolved after a final field inspection.

Within the geothermal well site area, it is reasonable to suppose that drilling to approximately 1,500 feet will result in intersection of fault zones, and in production of hot water from shattered volcanic rocks in and adjacent to the faults. Exact quantities and temperatures cannot be predicted. However, 150°F (or slightly higher) seems reasonable near the fault zones on the basis of temperature gradients in shallow wells and on regional considerations of the geothermal regime.

If yield from the first well is inadequate, it may be necessary to construct a second well. If the decision can be taken at once to do so, before the rig has been released, significant savings in rig costs for mobilization and demobilization can be achieved. This would presuppose that funding for 2 wells could be prearranged, even if only one were ever to be drilled.

The well should be drilled to design specifications to produce the fluid volume required. If upward of 700 gpm are sought, then a well 6-inches in diameter will likely be undersized. However, a 6-inch exploration well, into which temperature and air lift test tubing (ex. 2-7/8-inch) can be set, through a packer to isolate thermal from cold aquifers, can be drilled within the budget. A 6-inch well can be drilled to 200 feet depth at 9 to 12 inch diameter, 7-inch casing run and cemented and the hole diameter then reduced to 6 inches. It may not be necessary to case the hole to 200 feet depth, depending upon state regulations and conditions of the hole. These holes are commonly drilled for less than $25,000, on a per hour rather than a per foot drilling contract. The well would not be capable of production beyond 100 to 150 gpm. The casing could be removed, and the hole reamed and fully developed.

A production size well for 700+ gpm would require a different program. A general example is:

26-inch diameter to about 100 foot depth, with 20 to 22-inch conductor casing set.

17-1/2-inch diameter to the production zone, with 12-3/4 to 13-3/8-inch casing set.

12-1/2-inch diameter hole through the production zone, completed barefoot or with 8-5/8-inch slotted liner, possibly gravel packed. This hole design would quite possibly cost more than $60,000.

GeothermEx, Inc. 901 MENDOCINO AVE. BERKELEY, CA. 94707

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