RESEARCH TECHNICAL COMPLETION REPORT
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Geothermal Water and Power Resource Exploration and Development for Idaho

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Water Resource Research Institute
University of Idaho
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GEOTHERMAL WATER AND POWER RESOURCE EXPLORATION AND DEVELOPMENT FOR IDAHO

by

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ABSTRACT

Recent economic and political pressures to develop new energy sources that will have less adverse environmental effects and still meet the growing demand for power have focused discussion on the potential for developing natural steam and hot water sources for geothermal power. There is also significant interest in using hot waters for non-power purposes such as recreational swimming, fish farms, greenhouse operations and space heating of homes and buildings. This report presents a reconnaissance effort to define the geologic factors important in the evaluation of Idaho's geothermal potential. Limited information on the chemical contents and temperatures of hot water sources in Idaho was obtained to ascertain information useful in future exploration.

An attempt was made to identify the extent of hot water uses in Idaho. The pattern of use was studied and information obtained on the economic importance of the hot water as a State resource.

During the progress of the research a new State statute was passed and the legal responsibility of regulating and administering the geothermal resources was assigned to the Idaho Department of Water Administration. Future needed studies will thus be coordinated through that agency.

FOREWORD

The Water Resources Research Institute has provided the administrative coordination for this study and organized the interdisciplinary team that conducted the investigation. It is the Institute policy to make available the results of significant water related research conducted in Idaho's universities and colleges. The Institute neither endorses nor rejects the findings of the authors. It does recommend careful consideration of the accumulated facts by those who are assuredly going to continue to investigate this important field of geothermal power and water resources.

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INTRODUCTION

Late in 1970 and early in 1971 the writers and Dr. Mont M. Warner discussed approaches of research that would be valuable to the State of Idaho in the new field of geothermal power development. From this discussion an interdisciplinary team was organized which consisted of the following:

Dr. Clayton R. Nichols, Boise State College

Dr. Mont M. Warner, Boise State College

Prof. C.C. Warnick, University of Idaho

Prof. C.E. Brockway, University of Idaho

Dr. W.P. Barnes, University of Idaho

Dr. John Bond, Idaho Bureau of Mines and Geology

In May, 1971, the group submitted a research proposal to the Research Council program ("short term applied research" but under the general research program of the Council) at the University of Idaho. Dr. Clayton Nichols sought and received financial support for field work in southern Idaho from the Idaho Power company.

The original proposal contained the following objectives:

1. To identify the magnitude of hot water or steam sources needed for various sizes of power or hot water developments.
2. To identify non-power uses of geothermal waters and the economic potential of these uses in Idaho.
3. To study legal problems of geothermal water, particularly as they relate to state water rights.

4. To identify possibilities for nuclear explosions to aid in development of geothermal power in Idaho.
5. To study heat transfer characteristics in different rocks to identify long term or short term effects of introducing new water sources into the fractured area of thermal zones deep in the earth.
6. To identify the best locations in Idaho for geothermal and base temperatures in the high potential geothermal resource areas of the State of Idaho.

The scope of the project was narrowed to consider only items 2, 3 and 6 at the direction of the University of Idaho Research Council. It was then the intent to pursue the research as a three-year effort, but lack of funding from the Office of Water Resources Research and the decision for Idaho's efforts of investigation of geothermal power and water to center in the Idaho Department of Water Administration and the U.S. Geological Survey has made it necessary to terminate the research after one year.

During the progress of this research, there developed much interest in filing for geothermal power rights, and certain filings for water under the conventional water rights use program of the State of Idaho were made. The legislature and administration of the State recognized that new statutes were necessary to properly administer this resource. The authors of this report were contacted and made recommendations regarding the legislation and item 3 of the objectives was covered somewhat outside the scope of this study. Yet it is recognized that the legal aspects of geothermal development are so new that much research and operating experience will be necessary to meet the needs of the State in that realm of the problem.

The year of study thus resulted in two main thrusts: (1) A consideration of the geologic factors in the evaluation of Idaho's geothermal potential and (2) the assessment of the principal commercial uses of hot waters in the State of Idaho. The body of the report is divided into these two sections.

During the progress of the research, the Idaho State Ground Water Committee requested that a detailed bibliography of pertinent literature on the subject be developed; this report has attempted to assemble a bibliography of geothermal literature that will be useful to citizens and later investigators.

GEOLOGIC FACTORS IN THE EVALUATION OF IDAHO'S GEOTHERMAL POTENTIAL

Introduction

The economic feasibility of geothermal power production has been demonstrated conclusively at the Geysers in Sonoma County, California, and the search for similar, potent "dry steam" geothermal systems has provided the incentive for most of the "geothermal boom" in the western states. Although the earth has been described as a vast reservoir of heat energy, White (1969) has shown that it is only in relatively rare, localized areas with anomalously high heat flow rate and thermal gradient that the heat energy may be profitably extracted for power generation. Heat is dissipated at the surface of the earth at an average rate of only 1.5 micro-calories per cm^2 per second (one micro-calorie per cm^2 per second is one "Heat Flow Unit" or HFU), and this rate of energy output from the interior of the earth is several orders of magnitude less than the rate of energy reception from the sun. The "normal" rate of temperature increase with depth or geothermal gradient is $20^{o}C$ per km within the continental crust. Assuming a minimum required steam temperature of $200^{o}C$ and the normal geothermal gradient, a depth of 10 km (33,000 feet) would be required in order to attain $200^{o}C$. Surface ground water does not percolate to this depth on a significant scale, and geothermal waters have been shown on the basis of their isotopic composition (Craig, et al., 1956) to be predominately (>95%) heated ground water. Large convective hot ground water cells in high heat flow areas are known as geothermal zones and they provide the targets for geothermal power development.

The magnitude of the thermal anomaly and the rate of heat exchange with the ground water ciruclation permitted by the geologic setting lead to the establishment of a maximum or "base" temperature within each geothermal system. This base temperature and the volume of hot water and steam available for production from the system determine the type of utilization most suitable to each geothermal zone. Temperatures in the 250°C range are presently required for economic geothermal power generation. The presence of a geothermal system is usually indicated by surface manifestations such as geysers or hot springs, and the base temperature of the system may be predicted from a geochemical analysis of the thermal waters. Little doubt remains as to the accuracy and dependability of geochemical techniques in the preliminary evaluation of geothermal systems. At the present a geothermal system must be located through its surface manifestations before it may be evaluated by other techniques, and a question of fundamental importance remains. Can a high temperature geothermal zone exist without the usual surface indications, and if so, how can its presence best be detected? This question is especially relevant to Idaho, a state with over 200 hot spring areas, but no known geysers.

The high heat flows required for active geothermal zone development occur only in certain specific geologic environments, and the geothermal potential of an area may be assessed on a preliminary basis from the presence or absence of the regional geologic conditions responsible for abnormal heat flow. Recent technological advances reported by Gerber (1972) point toward the future feasibility of extracting the heat energy profitably from any major thermal anomaly whether or not a convective ground water system is naturally developed. In the total evaluation of Idaho's geothermal potential, it is thus necessary to assess the State's regional geologic situation in addition to examining its surface hot water manifestations.

Objectives

Major objectives of the geologic investigations were: (1) to locate the major geothermal systems within the State, (2) to predict their base or miximum temperatures at depth utilizing geochemical techniques, and (3) to develop generalizations concerning the "geologic habitat" of geothermal systems and apply them to Idaho's regional geologic setting.

Previous Geologic Investigations

Data on hot springs of Idaho have been tabulated by Waring (1965) and by Ross (1971). The latter reference includes a compilation of geochemical data as well as location, temperature and flow rate information. The distribution of thermal waters is reflected in a general way by the Federal government's classification of public lands with respect to their geothermal resource potential (Godwin, et al., 1971). A map showing the lands in Idaho, western Montana, Nevada, eastern Oregon, western Wyoming and northern Utah classified as having a geothermal potential are shown in Figure 1. Two types of designation were employed under the Geothermal Steam Act of 1970. The term "Known Geothermal Resource Area", KGRA, was used to designate areas in which "the geology, nearby discoveries, competitive interests or other indicia" would seem to warrant the expenditure of funds for geothermal ex-

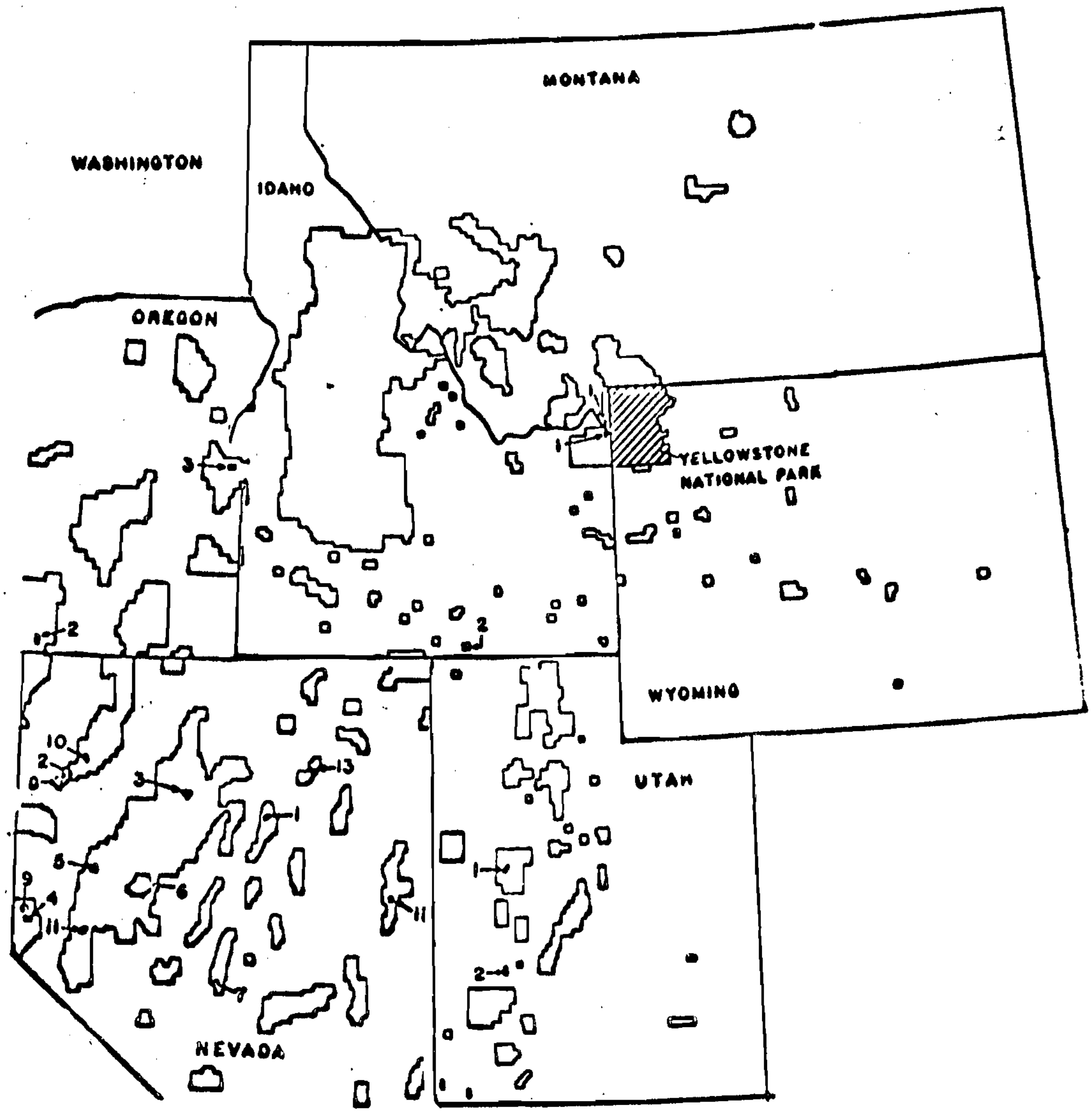

Figure 1. Lands classified as Known Geothermal Resource Areas are shown as numbered areas; Areas Valuable Prospectively are enclosed without numbers. Idaho has two KGRAs; the Yellowstone KGRAwith a total of 14164 acres, and the Frazier (Raft River) KGRA (#2) with a total of 7,680 acres. (From Godwin, et al, Classification of Public Lands Valuable for Geothermal Resources U. S. Geological Survey Circular 647, 1971.)

ploration. Only two KGRA's were designated in Idaho. These were the Yellowstone National Park and the Frazier (or Raft River) KGRA comprising twelve sections in Cassia County. In addition to KGRA's, the Geothermal Steam Act also provided for the retention of geothermal rights by the Federal Government upon disposal of lands determined to be "areas valuable prospectively" (AVP). Approximately 15 million acres in Idaho have been so designated.

Previous investigations of particular relevance to the understanding of the distribution of Idaho's thermal water include a number of hydrologic, geologic and geophysical studies of both a regional and local nature. The hydrology of the Snake River Basin has been discussed by Mundorff, et al. (1964). A review of the geology and hydrology of many of the ground water basins in Idaho is contained in Water Information Bulletins published by the Idaho Department of Water Administration. Individual bulletins of particular geothermal interest include #4, Ground-Water Resource of the Mountain Home Area, Elmore, County, Idaho, Ralston and Chapman (1968); #14, Ground-Water Resource of Northern Owyhee County, Idaho, Ralston and Chapman (1969); and #19, The Raft River Basin, Idaho-Utah, Walker, et al. (1970). The geology of the Island Park area has been mapped by Hamilton (1965) and Stearns, et al. (1939). Geologic mapping in the southeastern portion of Idaho by Mansfield (1920,1921, and 1927) has been supplemented by geophysical investigations such as the study by Mabey and Oriel (1971) which are useful in attempting to correlate hot spring distributions with volcanic activity. Mapping in the west central Snake River Plain by Malde, et al. (1963) is important to the understanding of thermal water distribution along the flanks of the western Snake River Plains.

General comprehensive discussions of geothermal systems, their operation and exploitation are presented in papers by White (1968 and 1969), White, Muffler, and Truesdell (1971), and Koenig (1970). Papers dealing specifically with the exploration for geothermal zones and geochemical prospecting include those by Combs and Muffler (1972), Koenig (1970), Crosby (1971), and Fournier and Truesdell (1970).

Method of Investigation

A comprehensive review of the literature concerning the distribution and geochemistry of hot springs and wells of Idaho and a compilation of published and unpublished geologic data available for these hot spring areas was made possible through a grant from STAR funds. Limited field investigation of selected not springs areas and additional geochemical analysis of hot water were undertaken during the summer of 1971 by Idaho Power Company through a grant to Dr. Mont Warner and Clayton Nichols, Department of Geology, Boise State College.

Criteria utilized in the present investigation for the identification and economic evaluation of geothermal zones were generally similar to those techniques listed by Godwin, *et al.* (1971). These geologic considerations included:

> ...the measurement of surface temperatures of springs and wells, an examintation of the geochemistry of thermal water flowing as an indicator of maximum temperatures to be expected at depth, a mineralogical examination of surface alteration produced by thermal springs as an indicator of both the intensity and extent of leakage from thermal zones, and the regional geologic setting as it influences the reservoir characteristics and possible heat source for the geothermal zone.

Utilizing these criteria, five areas were originally selected for investigation during the summer of 1971. These areas were:

1. Raft River Basin near Bridge, Cassia County
2. Worswick Hot Springs near Fairfield, Camas County
3. The Mt. Bennett Hills Front near Mountain Home, Elmore County
4. Bruneau-Oreana-Grandview Area, Owyhee County
5. Boiling Springs Area, Valley County

Additional information gathered from interviews with local residents and a review of regional geologic considerations warranted a limited study of two more areas:

6. Caribou Range in Caribou and Bonneville Counties
7. Island Park Area, Fremont County

Water samples were collected and stored in polyethylene containers. Storage times prior to analysis by Hibbs Laboratories of Boise, Idaho, were in no instance longer than two weeks. Samples with a high silica content were diluted to one part in ten parts distilled water immediately upon collection to prevent silica polymerization. Temperatures were predicted primarily by means of temperature vs. SiO_2 curves as published by Fournier and Rowe (1966). Calculations utilizing the atomic ratio of Na/K (Fournier and Truesdell, 1970) were also attempted with only partial success in correlating these results with SiO_2 predicted temperatures.

Information obtained in the investigation was forwarded to the Boise office of the U.S. Geologic Survey for utilization in their current investigation of geothermal water in the State of Idaho.

Results of the Geologic Investigation

The first phase of the investigation involved the selection and geochemical sampling of five of the most promising geothermal areas described previously in the work of Ross (1971) and then the two additional areas. The location, temperature, and chemical data for the original five thermal areas are presented in Table 1. These five areas are situated in three distinctive geologic environments: The basin and the range province, the Idaho Batholith, and the western Snake River Plain (Figure 2).

The Basin and Range Province

The thermal waters of southeastern Idaho are distributed along generally north-south trending fault zones which are characteristic of the Basin and Range Province. The Raft River Valley in Cassia County near Malta which contains perhaps the most impressive thermal anomaly in the State illustrates the Basin and Range occurrence of thermal water. The geology of the Raft River Valley has been mapped in detail by Anderson (1931) and by Nace, *et al.* (1961). Major high displacement, north-south trending faults provide the thermal fluids produced from several 400 foot-deep wells on the west side of the main valley floor. The Raft River Valley is a westward-tilted, down-faulted block, and the Cotterell Range on the west side of the valley is a horst (up-faulted block) which also has a westward tilt. Gravity profiles by Cook, *et al.* (1964) indicate 4,000 feet of sedimentary fill within the valley floor.

Of the five areas initially studied, the Raft River thermal waters are the closest chemically to the composition of typical geothermal brines.

Table 1. Temperature and Chemical Data

Number on Figure 2	Number in Waring (1965)	Name	Location	Measured Temp °C	SiO_2 ppm	Predicted Temperature C [1]
1	184	Raft River - Crank's Well, Frazier KGRA	Sec. 23,T.15S., R. 26E, Cassia County	98°C	147	160
2	136	Worswick Hot Springs	Sec.28, T.3N., R. 14E., Camas County	88°C	150	163
3	---	Walker Well #1 Mt. Bennett Hills	Sec. 8, T.4S., R. 9E, Elmore County	63°C	134	156
4	167	Indian Bath Tub Bruneau Area	Sec. 3, T.8S., R. 6E., Owyhee County	38°C	70	118
		Blacks' Well	Sec. 9, T.7S., R. 6E., Owyhee County	49°C	118 [2]	150
5	38	Boiling Spring	Sec. 22, T.12N., R. 5E., Valley County	88°C	110	144

[1] Temperature predicted on the basis of the solubility of quartz from curves published by Fournier and Truesdell (1970).

[2] Data from Ross (1971).

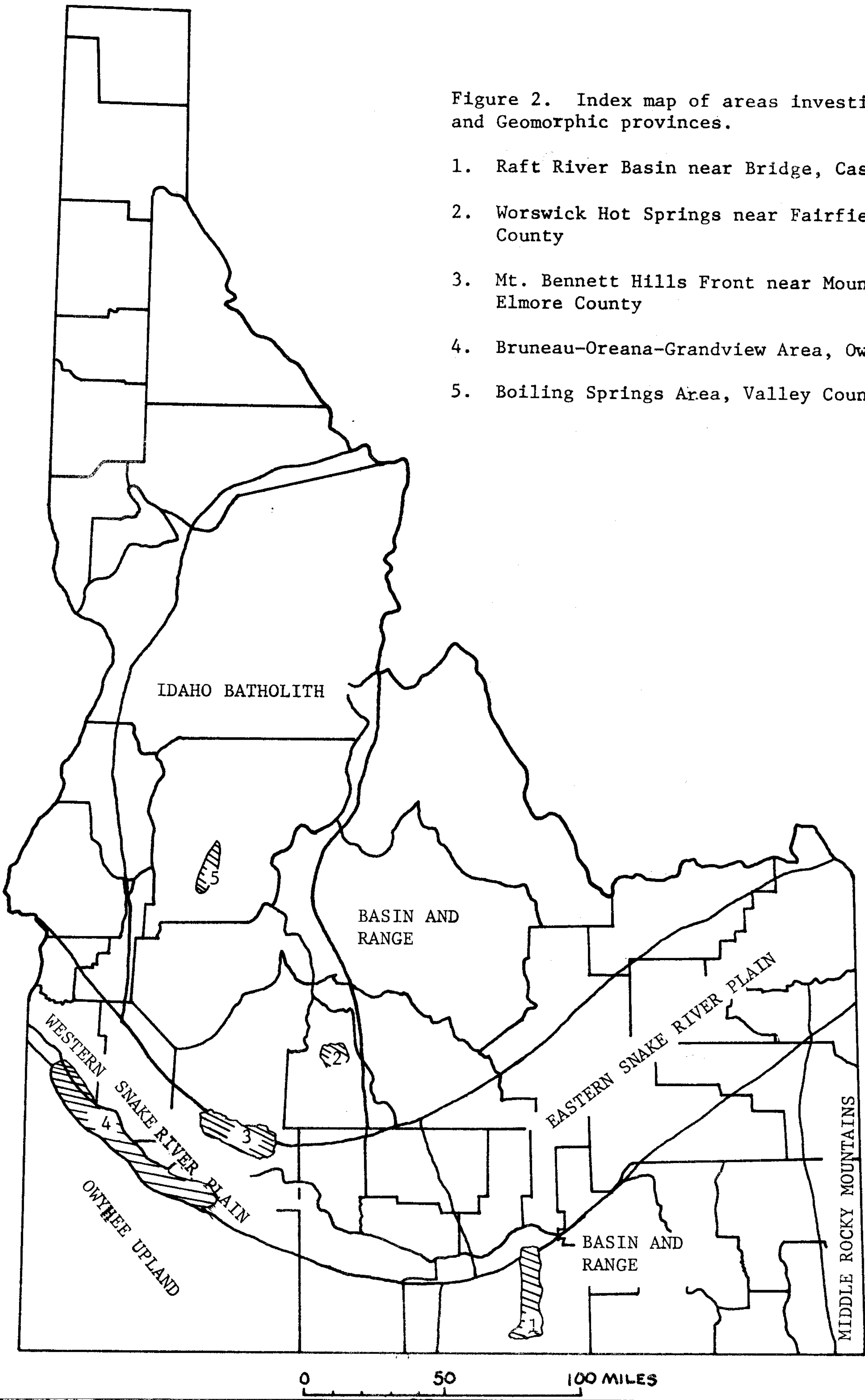

Figure 2. Index map of areas investigated and Geomorphic provinces.

1. Raft River Basin near Bridge, Cassia County
2. Worswick Hot Springs near Fairfield, Camas County
3. Mt. Bennett Hills Front near Mountain Home, Elmore County
4. Bruneau-Oreana-Grandview Area, Owyhee County
5. Boiling Springs Area, Valley County

The high chloride content of the water (1,700 ppm) is indicative of a "wet" geothermal system (White, et al., 1971). The relatively rare dry steam systems characteristically have a low chloride content (less than 50 ppm Cl). The silica contents of the thermal waters from the two wells indicate a temperature at depth of at least 160°C, but the relatively high atomic ratio of Na/K (greater than 20) may indicate a low temperature system, probably less than 200°C.

The presence of water near the boiling point in the Raft River wells has attracted considerable economic interest, and twelve sections have been designated the Frazier KGRA. The water from the southernmost of the two wells is being utilized in a greenhouse operation, but leasing interest in the area has been motivated primarily by interest in the geothermal power producing potential. In spite of the relatively low geochemically predicted maximum temperatures (less than 200°C) and the apparent wet nature of the system, the Raft River area still constitutes the State's best substantiated geothermal zone. Anomalous silica values for both ground and river water from the main-south portion of the valley indicate extensive leakage of silica-rich thermal fluids along the north-south trending fault zones.

The low temperature, wet geothermal system here may be the result of the area's unique geologic setting. Stone (1969) has theorized that three major regional tectonic zones intersect near the north end of the Raft River Valley. Rift zones of the western and eastern Snake River Plain intersect the north-south faulting of the Raft River Valley at its intersection with the east-west trending plain of the Snake River. Above average heat flow at this intersection may be responsible for the thermal waters in the Raft River Valley.

The other major north-south trending valleys along the Idaho-Utah line are also thermally active and possess a relatively undeveloped geothermal potential. The thermal springs of Utah occur in a north-south trending zone which is reflected in a general way by the Federal government's designation of AVP for geothermal resources as shown in Figure 1. This distribution of thermal water as mapped by Mundorff (1971) coincides with the tectonically active region known as the Intermountain Seismic Belt (Shar, et al., 1972). This zone of above average seismic and thermal activity extends northward into Idaho in the Cache Valley region of Franklin County near Preston. Recent geophysical investigations by Stanley (1972) revealed a 6,000 foot depth of sedimentary fill within the down-faulted valley floor. Information on thermal water in the area is sparse, but unsubstantiated reports indicate a greater distribution of hot well water than that previously reported in the literature. The area is slated for investigation during a joint U.S. Geologic Survey-State Water Administration geothermal investigation now in progress.

The belt of seismic activity in eastern Idaho is not continuous between the Cache Valley area and the seismically active areas of southwestern Montana, but microseismic swarm activity has been detected at Caribou Mountain, Bonneville County, and in the vicinity of Palisades Reservoir (Prof. Edmund Williams, Ricks College, Rexburg, Idaho, personal communication, June, 1972, and Sbar, et al., 1972). Carbonate-rich hot springs occur at Soda Springs in Caribou County and springs with a high temperature geochemistry occur near Palisades Reservoir. Other hot springs in eastern Idaho related genetically to the Basin and Range environment include Lava

Hot Springs, Bannock County, and Lidy Hot Springs, Clark County, on the northern side of the eastern Snake River Plain. The majority of the hot springs in southeastern Idaho have a geochemistry very similar to that of the springs along the Wasatch Fault Zone and Intermountain Siesmic Belt in Utah.

The only water sampled which possessed a water chemistry characteristics of a true geothermal system was that from the Raft River wells. Based on the relatively low predicted maximum temperatures and wet nature of the system, the Raft River area would appear to have only a limited power-producing potential best suited to power generation utilizing a heat exchanging technique such as the "Magma Max" process.

Hot water within the Basin and Range Province might be expected to display a more variable chemistry than water from the batholith or western Snake River Plain. The water chemistry reflects both the temperature and the chemistry of the deep wallrock encountered during circulation. The variable sedimentary lithology of the province will result in a variable total dissolved solids content of the hot water.

Western Snake River Plain

Several extensive thermal areas in southern Idaho are related to the west-northwest trending fault zones paralleling the north and south flanks of the western Snake River Plain rather than to the Basin and Range structure. The Mt. Bennett Hills thermal zone is an extensive area of hot springs and wells which parallel the southwestern front of the Mt. Bennett Hills east of Mountain Home in Elmore County. Hot springs in the area such as Latty Hot Springs occur at the intersection of north-south faulting with the west-northwest trending faults which define the northern flank of the western Snake River Plain. Artesian wells in the area produce hot water from sedimentary rocks of the Glenns Ferry group of Quaternary Age near these fault intersections.

Water from the Walker Well near Latty Hot Springs in Elmore County produces 63°C water under artesian pressure from the Glenns Ferry Formation. The silica content of the water (134 ppm) indicates 156°C temperatures at depth. The measured specific conductance of the water (350 micromhos compared with 5,600 for the Raft River wells) indicates the low mineralization of the water.

The Grandview-Oreana-Bruneau thermal area of Owyhee County is a major area of thermal water on the southern flank of the western Snake River Plain. Thermal waters averaging 35-40°C are produced from a seventy-mile long and twelve-mile wide frontal zone separating the granitic core of the Owyhee Mountains from the Snake River Plain proper. No wells in the area have encountered steam or water at the boiling point. The maximum temperature encountered to date was 81°C in the Forman well (Sec. 19, T 4S, R 2E). The maximum temperature predicted on the basis of silica content for the wells of the region is 150°C for the Black well (Sec. 9, T 7S, R 6E).

On the basis of calculated and observed temperatures there is no indication of the development of medium to high temperature thermal water within the western Snake River Plain. Deeper circulation near the base of the basalt-like sediment filling of the plain to depths of 5 km (15,000 feet) would be sufficient to explain the occurrence of even 200°C water without recourse to localized intense heat sources. Although the conventional power producing potential of the area appears to be extremely limited, the total energy available from the extensive thermal anomalies on both flanks of the plain is impressive. Future deep drilling between presently known areas of hot water will possibly reveal additional zones of hot artesian water along the frontal fault zones. The low mineral content combined with the artesian pressure make these waters ideally suited for agricultural purposes.

The Idaho Batholith

Most of the area in Inaho designated an AVP by the Federal government lies within the Idaho Batholith. Hot springs occur throughout the batholith but are concentrated in several areas such as the valleys of the Middle and South Forks of the Salmon River, the North and Middle Forks of the Payette River and the South Fork of the Boise River. Within the southern portion of the batholith, Worswick Hot Springs on Little Smoky Creek north of Fairfield in Camas County (Sec. 28, T 3N, R 14E) was chosen for study from the compilation by Ross (1971). The springs are situated within an area of approximately 15 acres of highly altered granitic rock. The deposition of silica by the cooling waters in the vicinity of the springs and the surface temperature of the springs (88^{o}C) combine to make this one of the more impressive hot spring areas in the batholith. The silica content of the water (150 ppm) was the highest recorded during the present study and is higher than any reported by Ross.

Boiling Springs and Vulcan Hot Springs are the best known of seventeen hot springs located along the Middle Fork of the Payette River and the

South Fork of the Salmon River in Valley County. The springs occur along north-south trending drainages which appear to be structurally controlled.

The main detriment to the utilization of the extensive springs of the batholith for other than recreational or limited space heating is the absence of favorable reservoir conditions. The fractured granite within fault zones lacks the porosity required for any high volume use such as power generation even if adequate temperatures are attained. The batholith does appear to provide the necessary environment for the Plowshare type of nuclear stimulation and power production (Gerber, 1972). By means of an array of nuclear blasts detonated at a depth of 8,000 feet, a cavity of fractured rock would be created in an area with a suitable thermal gradient. Water would be injected into the cavity where it would be flashed to steam by the naturally heated rocks. Production wells would be drilled into the top of the cavity. Success of the procedure would depend on the identification of local areas within the batholith which possess a suitable thermal gradient and an adequate water supply for injection into the hot, dry rocks. The technology necessary for this type of power production is being developed, but environmental and economic considerations seem to preclude its application for the present (especially in the South Fork of the Salmon River).

Conclusions

Based on a preliminary examination of the more promising reported hot spring areas, the total geothermal energy available for utilization in Idaho is great, but the potential for power generation utilizing conventional steam hardware is very limited. The original five hot spring and/or hot well areas investigated during the summer of 1971 all have a geochemistry characteristic of hot water geothermal systems with a base temperature of less than 200°C. This finding is consistent with the regional geologic situation. The vast majority of the hot springs in Idaho, as elsewhere, simply reflect a higher than normal regional heat flow and deep ground water circulation permitted by fault zones. Blackwell (1969) has used the term "Cordilleran Thermal Anomaly to describe the "broad central zone of above average heat flow in the Basin and Range, Northern Rocky Mountain and Columbia Plauteau Provinces". Heat flow data from the Wallace District in northern Idaho yielded an average value of 2.3 HFU (Blackwell, 1969). Measurements reported south of Murphy Hot Springs, Owyhee County, in northernmost Nevada by Sass, et al. (1971), yielded a value of 3.76 HFU and a calculated thermal gradient of 43°C/km. Data from the central and southern portions of Idaho are non-existent, but the State apparently is transversed from north to south by this zone of above average heat flow.

Deep ground water circulation in this broad region of high flow is sufficient to explain the less than 200°C maximum water temperatures predicted by the present study. With a geothermal gradient of 40°C per km, a maximum depth of circulation of 2 to 3 km would be sufficient to explain most of the region's hot springs. The truly regional extent of thermal waters in Idaho and their varied geologic occurrences support the conclusion that the vast majority of Idaho's hot springs can be explained in terms of the regional heat flow and fault distribution. The springs are not associated with the intense, near surface heat sources characteristic of high temperature geothermal systems.

REGIONAL GEOLOGIC FACTORS RELEVANT TO THE DISTRIBUTION OF GEOTHERMAL SYSTEMS

The wide distribution of relatively low temperature hot springs in Idaho and the absence of high temperature systems indicate that a rather rare coincidence of geologic conditions is required for the development of an active, moderate to high temperature geothermal system. The second phase of this investigation involved a consideration of the geologic conditions required for the development of these intense geothermal systems.

The close association between geothermal zone activity and volcanic activity is universal. Although thermal fluids may be derived from sedimentary reservoirs, the ultimate source of the heat is closely associated, hot igneous rock or magma. The heat exchange between rock and ground water takes place at relatively shallow depths as the large scale vertical circulation of water is limited to depths of several miles. Not all volcanic activity has associated geothermal zone development. The characteristic mode of emplacement or eruption of the magma or lava varies with its chemical type and this mode of eruption determines the probability of geothermal zone development. Basaltic eruptions originate at depths greater than 30 km in the upper mantle, and a rapid upward movement of the relatively fluid magma occurs through fissures to the surface. The original high heat content of the basaltic lava is rapidly dissipated by surface eruptions, and basaltic eruptions in continental areas do not appear conducive to geothermal zone development.

If a heat source beneath an area of continental crust is potent enough to cause magma generation and associated volcanic activity, the likelihood of geothermal zone development is much greater. Magmas of an intermediate to silicic composition thus generated are much more likely to serve as the near surface heat source required, and by their very existence they reflect the presence of a near surface high thermal gradient. Within ocean basins, an intense thermal gradient may extend to the surface without associated silicic volcanism simply because there is no continental material to melt. Such is the situation at Iceland which is underlain by the high heat flow of the Mid-Atlantic Rise. In continental areas the intense, localized thermal anomalies which drive the convection cells of high temperature geothermal systems will be uniquely associated with crustal magma generation and associated silicic volcanism.

Silicic plutonism or vulcanism in a locality constitute no guarantee of a presently active geothermal zone as the heat may already have been dissipated and the convection cell responsible for the heat dissipation may have ceased to function. Most intense geothermal fields are normally associated with presently active volcanoes or volcanic fields that have been active during recent time.

Not only must a potent heat source be available, but it must be accessible to relatively shallow convective ground water circulation. Faults provide the avenues for the circulation required, and there is considerable evidence to indicate that the faulting must be active in order to maintain the permeability required. Nichols (1970) has noted the "self-sealing" effect of precipitation from thermal solutions in faults of the Pathe Geothermal Zone, Hidalgo, Mexico. Carbonate minerals tend to precipitate during the descent and warming of ground water on the margins of a thermal zone and silicate minerals tend to form during the ascent and cooling of water within the zone. Investigations of major geothermal zones have shown them to be the locus of intense microseismic activity (Clacey, 1968; Hamilton and Muffler, 1972; Tobin, et al., 1969; and Ward and Bjornsson, 1971). The cause and effect nature of the relationship between microseismic activity and geothermal zone development is not clearly understood at this time, but the association has been varified to the extent that the field recording of microseismic activity appears to have considerable potential in the verification of the existence and lateral extent of geothermal zones.

An application of these geologic requirements for high temperature geothermal zone development to the geologic situation in Idaho explains the observed absence of high temperature phenomena in much of the State. The western Snake River Plain is dominated by basaltic volcanism. The youngest dated silicic rocks in the area have a K/Ar age of 9 to 13 m.y. (Armstrong, 1971). The primary emplacement of the Idaho Batholith occurred during Cretaceous time (100 m.y. B.P.). More recent "thermal events" have occurred including emplacement of silicic rock of Tertiary Age but none of this activity appears to have occurred during late Pleistocene or Recent time.

The situation in the eastern Snake River Plains and Basin and Range Province is more complex. Silicic volcanic rocks have been mapped in Caribou County by Mansfield (1921) who believed they were equivalent in age to the rhyolitic eruptive rocks of the Island Park area. The eruptions of rhyolite in the vicinity of the Island Park Caldera have been assigend a Quaternary Age by Hamilton (1965). They are the youngest known silicic volcanic rocks in Idaho. This presence of young rhyolitic volcanism and microseismic action in eastern Idaho indicates a favorable environment for geothermal zone development. The absence of reported high temperature geothermal phenomena in these areas must be explained if the geothermal potential is to be seriously considered. Two possibilities exist - either the surface indications are present but not reported in the literature or they may be present at shallow depth but masked by near surface ground water conditions.

HOT WATER USE IN IDAHO

Recognizing the widespread use of hot water in Idaho for recreational and commercial use, a survey was conducted in August, 1971, to determine the magnitude of present hot water use and the economic importance to the State.

The report by Ross (1971) on Geothermal Potential in Idaho lists over 200 known geothermal sites within the State which are or have been used for recreation and seven developments for home heating or commercial use. Most of the uses other than recreational were listed as greenhouse developments with only two large scale developments for home heating purposes.

In the current survey, 35 developments were visited and managerial personnel or owners were interviewed. Figure 3 shows the locations within the State of the hot water development interviewed as well as the developments indicated by Ross's report. Table 2 gives identifying facility number and location.

Some of the recreational sites had been abandoned or were used very little with no maintenance. In general the recreation oriented developments are seasonal and many are family enterprises. Table 3 lists the information obtained by interview with managers or owners. Some owners were reluctant to divulge information on their developments.

The recreation oriented developments are generally older facilities, some having been in use in the late 1800's. The average number of years in operation for the developments interviewed was about 46 years. Capital

Figure 3:
THERMAL SPRINGS AND WELLS
IN IDAHO

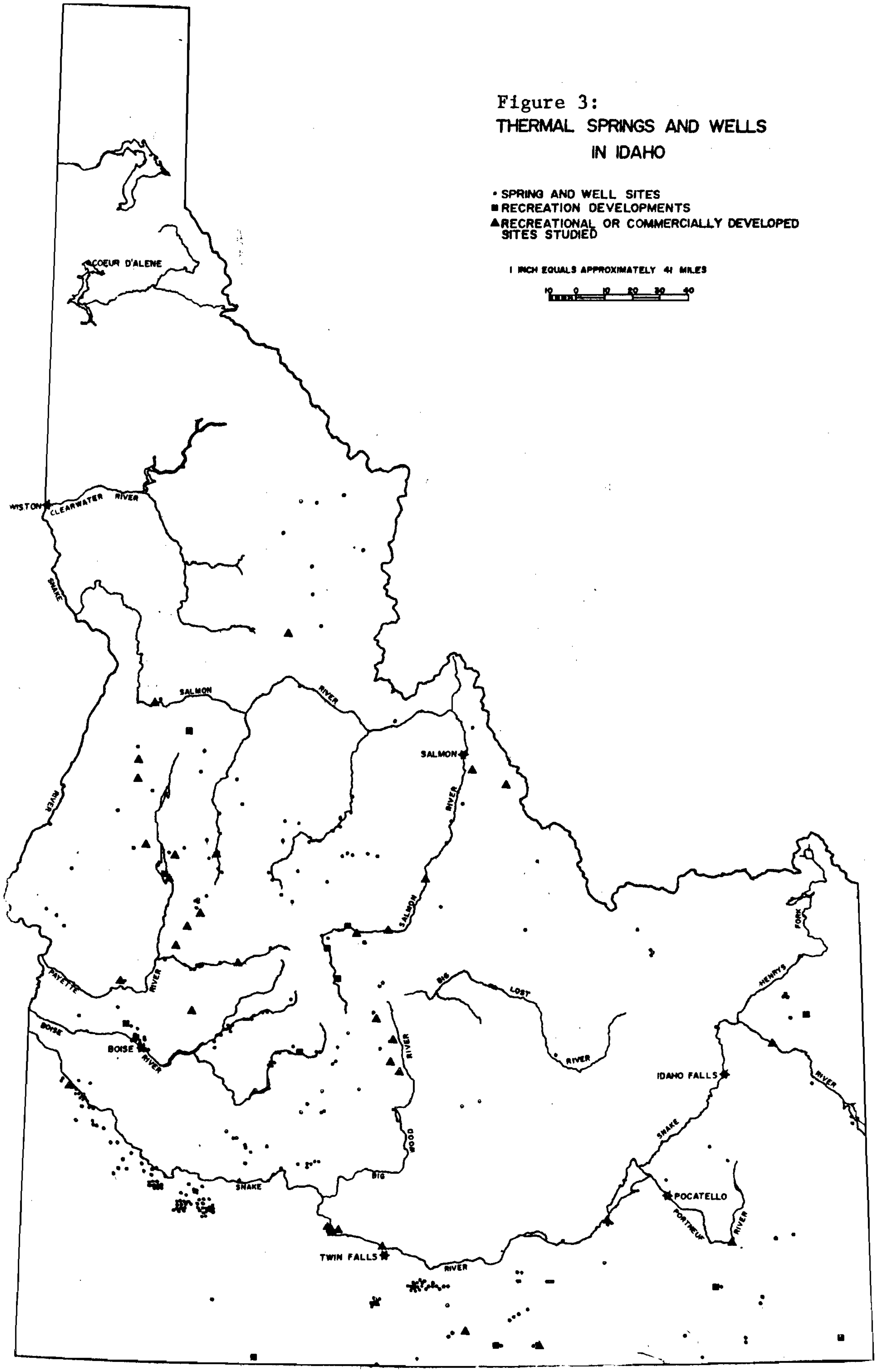

Table 2: Location and Name of Geothermal Developments

Number of Facility	Name	County
1	Royal Catfish Industries, Inc.	Twin Falls
2	Mrs. Cranks-Raft River	Cassia
3	Clarendon Hot Springs	Blaine
4	Brandts Hot Springs-Ketchum	Blaine
5	Hiawatha Hotel, Hailey H.S.	Blaine
6	Indian Hot Springs, Inc.	Power
7	Miracle Hot Springs	Twin Falls
8	Nat-Soo-Pah	Twin Falls
9	Banbury Hot Springs	Twin Falls
10	Sligar's	Twin Falls
11	Easley Store & Plunge	Blaine
12	Oakley Hot Springs	Cassia
13	Ward's Greenhouse	Boise
14	Badley Hot Springs	Valley
15	Sullivan's	Custer
16	White Licks Baths & Camping	Idaho
17	Sharkies Hot Springs	Lemhi
18	Cascade City Pool	Valley
19	Health Spa Hot Springs	Gem
20	Salmon Hot Springs	Lemhi
21	Haven Lodge (Lowman)	Boise
22	Riggins Hot Springs	Idaho
23	South Fork Plunge	Valley
24	Frank Garcie	Adams
25	Challis Hot Springs	Custer
26	Warm Springs Resort	Boise
27	Robinson Bar	Custer
28	Givens Hot Springs	Owyhee
29	Silver Springs Plunge	Valley

Table 2 (cont.)

Number of Facility	Name	County
30	Red River Hot Springs	Idaho
31	Zims Resort	Adams
32	Terrace Lakes	Boise
33	Heise Hot Springs, Inc.	Jefferson
34	Lava Hot Springs	Bannock
35	Stanley Hot Springs	Custer

Table 3. Geothermal Development in Idaho--Hot Water Uses

Number of Facility	County	Type of Development	Years in Operation	Total Capital Investment	Length of Season (months)	No. of Employees	Water Supply
1	Twin Falls	Catfish farming	1.5	$ 20,000	12	2	1800gpm @42°C
2	Cassia	Agriculture	3	70,000	9	2	126gpm @100°C
3	Blaine	Resort	30-40	100,000*	12	2	100gpm @52°C
4	Blaine	Home heating & pool	44	100,000	12	1	750gpm @83°C
5	Blaine	Pool	56	68,000*	12	2*	100gpm @58°C
6	Power	Resort	56	750,000	5	8	2000+gpm @32°C
7	Twin Falls	Health Spa	13	52,000	12	2	300gpm @54°C
8	Twin Falls	Resort	42	70,000*	6	7	@37°C
9	Twin Falls	Resort	51	70,000*	5	5	600gpm @55°C
10	Twin Falls	Resort	16	100,000*	8	4	120gpm @74°C
11	Blaine	Resort	30-40	60,000	3.5	5	90gpm @37°C
12	Cassia	Health & Resort	5	35,000	12	2	10gpm @46°C
13	Boise	Greenhouse	3	12,000*	12	1	300gpm
14	Valley	(abandoned)					40gpm @38°C
15	Custer	(closed)					200gpm @41°C
16	Idaho	Baths & camping	?	1,000		0	35gpm @68°C
17	Lemhi	Pool	1800's	2,000*	Summer	2	200gpm
18	Valley	Pool	1950's	6,000*	Summer	1	@41°C
19	Gem	Pool		10,000*		1*	75gpm @66-74°C
20	Lemhi	Resort	28	100,000	Summer	1	400gpm
21	Boise	Swimming & home heat	15	70,000*	Summer	2*	75gpm @58°C
22	Idaho	Health resort	90	135,000	12	2	50gpm @42-50°C
23	Valley	Forest Campground	?	30,000*		2*	@54°C
24	Adams	Pool	10*	35,000*		2	61gpm @32°C
25	Custer	Resort	83	25,000*	12	2	1500gpm @51°C
26	Boise	Resort	1800's	120,000*		4	300gpm @43°C
27	Custer	Resort	1800's	90,000	12	8	40gpm @53°C
28	Owyhee	Pool	20-30*	60,000*		2*	35gpm @45°C
29	Valley	Resort	15	100,000	5	3	450gpm @39°C
30	Idaho	Resort	68	50,000	6	4	20gpm @54-63°C
31	Adams	Resort	44	120,000	12	6	100gpm @63-66°C
32	Boise	Resort	3	150,000*	12	8	
33	Jefferson	Resort	72	150,000	12	12	50gpm @50°C
34	Bannock	Resort & Health Spa	68	1,500,000	12	15	1500+gpm @38-62°C
35	Custer	Pool	1800's	2,000*	Summer	0	400gpm @19°C

*Estimate

investment ranged from practically nothing to $1,500,000 at the Lava Hot Springs resort in southeastern Idaho. The capital investment for several of the resorts was estimated in cases where the owners were not available or were reluctant to give estimates. A total of $4,263,000 in capital investment was estimated for the 33 operating developments including the home heating and agricultural developments. About 60 percent of the sites investigated were year round enterprises with the resort areas adjacent to winter sports developments or more populous areas. A total of 120 people were employed either full-time or part-time at the 33 facilities reporting. Some resorts were family enterprises, and the total number of employees included several members of a family. It is estimated that these establishments provide about 90 man-years of employment in the State. No estimates could be made of the total annual income for all reporting developments.

Eighteen of 24 establishments indicated that the present water supply was adequate for expansion. However, some indicated that recent restrictions by the Idaho State Department of Health and Environmental Protection on chlorination of public swimming pools would hinder or prevent any expansion of facilities. Thirteen of 27 reporting districts indicated plans to expand or improve facilities in the near future. Water supplies for existing facilities ranged from 10 gpm to 2,000 gpm and ranged in temperature from 37^{o} to $100^{o}C$.

It is recognized that not all of the recreational and commercially developed hot water sources were visited in this study. However, 37 sites were surveyed and the results reported on 35 locations. The majority of the larger recreational developments were investigated. Ross's report lists four known development for home heating and three for greenhouse use. Only one facility, Bald Mountain Hot Springs which is used to heat 50-55 homes and supply a public pool, was evaluated in this study. The other major development for space heating is in the City of Boise where 200 houses and 10-12 businesses are heated from a supply of 1,200,000 gpd of 170^{o}F water. (This is reported in the Journal of the West, "Heat from the Earth's Surface: Early development of western geothermal resources," by Merle W. Wells, 1971.) Several smaller uses of hot water are known to be operating in conjunction with recreational uses. Greenhouse developments are in operation on a commercial basis in the City of Boise, near Garden Valley in Boise County, and in Cassia County near Bridge. Tomatoes and cut flowers are the usual crops for these development.

Many hot water wells which are used for only irrigation have been drilled in Owyhee and Elmore Counties and their value as hot water sources at this time is small or the hot water may be a hindrance to irrigation in some cases. However, the potential for use in space heating is great and the development of greenhouse facilities should increase as the demand for agricultural products amenable to greenhouse culture increases. The use of hot water for year round production of certain species of fish is now being practiced near Twin Falls and plans for additional expansion are underway. With a cold water source, trout can be grown initially and catfish or other warm water species can be grown in the tailwater from the trout facility supplemented or warmed by a hot water source. Several owners of hot water sources in the Bruneau-Grandview area have expressed an interest in this type of development. Additional expansion of the health spa type of development can be expected. Several facilities now advertise as health spas and with the growth of tourism and resort developments, this type of activity should increase.

It is estimated that at this time, the capital investment in natural hot water related facilities amounts to in excess of $5,000,000 and provides full or part-time employment for 150 or more persons.

CONCLUSIONS AND RECOMMENDATIONS

The brief geological evaluation indicates that the power producing potential of the western Snake River Plain and the Idaho Batholith does not appear to be significant in terms of conventional generating techniques. The potential of the Basin and Range Province and the eastern Snake River Plain also appears to be minimal in terms of previously reported surface manifestations. These latter areas as pointed out in the data of this report do appear to be a more favorable geologic environment for the geothermal zone development. It is entirely possible that local detailed geological, geochemical and geophysical investigations in selected areas of eastern Idaho may reveal geothermal zones. More detailed geologic investigation and a drilling program will be necessary to further define the geothermal power potential.

A very limited study of the legal problems and the passage of a new administrative statute for administering geothermal power development indicates much need for further research.

The investigation of hot water uses has revealed some interesting information. Recreational uses at hot spring resorts appear to be somewhat depressed. Many of the sites have not made improvements to keep up with the desires and needs of the people. A constraint in further development is the requirement of chlorination of the hot water used by the public for swimming or as a health spa. There were indications in the survey of intentions to expand facilities.

An area of hot water use that appears to have much more potential is for home heating and commercial greenhouse culture of food and flowers. A very new use that has recently shown promise is using hot water to mix with other waters in raising catfish. More development and economic information should be sought to further exploit these new uses of hot water in Idaho.

The Water Resources Research Institute will welcome future opportunities to study more specific facets of the research problems that will need to be solved before a geothermal power industry is developed within Idaho.

For the use of future investigations and particularly to the benefit of the Geothermal Water Subcommittee of the Idaho State Ground Water Committee, the bibliography of this report is presented as a working tool.

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