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BEFORE THE ARIZONA CORPORATION COMMISSION

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IN THE MATTER OF THE APPLICATION OF NAVOPACHE ELECTRIC COOPERATIVE, INC. FOR APPROVAL OF RENEWABLE ENERGY STANDARD PLAN AND TARIFFS	DOCKET NO. E-01787A-07-0576 **COMPLIANCE**

Navopache Electric Cooperative, Inc. is hereby filing the Black and Veatch study and recommendations in compliance with Decision No. 70699 dated January 20, 2009.

RESPECTFULLY SUBMITTED this 11th day of February, 2009.

By ______________________

John Wallace
Grand Canyon State Electric Cooperative Assn. Inc.

Original and thirteen (13) copies filed this 11th day of February, 2009, with:

Docket Control
Arizona Corporation Commission
1200 W. Washington
Phoenix, AZ 85007

Arizona Corporation Commission
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GEOTHERMAL ASSESSMENTS FOR THE NAVOPACHE AND MOJAVE ELECTRIC COOPS, ARIZONA

for

BLACK & VEATCH

Walnut Creek, California

by

GeothermEx, Inc.

Richmond, California, USA

DECEMBER 2008

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ILLUSTRATIONS

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SUMMARY

Most of the conventional hydrothermal resources within Arizona remain at the exploration stage of development. Typically, these resource areas have been investigated using geochemical, geological, and sometime geophysical methods. The risks associated with developing commercially productive wells will remain high until discovery and confirmation drilling have been completed. EGS development eliminates some of the risk associated with discovering and confirming a conventional hydrothermal resource, since the primary requirement of EGS development is the presence of useful temperature. However, the ability to hydraulically stimulate rock to create an effective and long-lasting artificial heat exchanger remains a significant challenge owing to the immaturity of EGS development worldwide.

Navopache Area

Within the Navopache service territory, there is one conventional hydrothermal resource with power development potential: Lower Frisco Hot Springs, located in New Mexico, in the southeastern part of the Navopache area. Although this area remains poorly characterized, it has favorable resource temperatures inferred from geothermometry (130 – 150°C), the possibility of a relatively large natural discharge rate, favorable structure and hydrogeologic setting, and is located within 20 miles of a major N-S transmission line roughly paralleling the Arizona-New Mexico border. All of these suggest that the Lower Frisco resource is an attractive prospect area for conventional hydrothermal development.

There is also EGS potential within the Navopache service territory. Such a development would probably take the form of an EGS doublet (one producer and one injector) or a triplet (a central injector flanked by two producers) to develop something on the order of 5 MW of power. Maps provided by Navopache suggest that some land may be available for this type of development around Nutrioso. Data from the Alpine 1 core hole suggest that temperatures of 300°F should be reached at a depth of approximately 10,000 feet. While this is relatively modest temperature for

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3) Gillard Hot Springs – This site has characteristics similar to the Clifton area, and, ideally, could be investigated jointly with Clifton. In this area also, the cooperation of Phelps Dodge would be highly desirable.

4) Verde Hot Springs – This resource could be capable of supporting a development based on relatively low-temperature production (in the range of 120° to 150°C. Though somewhat remote, the site has reasonably favorable conditions for exploration and development.

In addition, the Hillsboro Warm Springs area in New Mexico presents an attractive prospect, based primarily on favorable temperatures estimated by geothermometry (~120°C) and its location relative to transmission lines.

Mojave Area

In progress

Exploration and Development Timelines and Costs

Most of the conventional hydrothermal resources discussed herein remain at the reconnaissance exploration stage; that is, the first "discovery" and the next one or two "confirmation" wells have yet to be drilled. It is anticipated that the exploration and initial deep drilling phase (including the discovery well and at least one confirmation well) for projects identified herein may cost between $1.5 million and $6 million (with variations in drilling cost accounting for most of this range). The time required to complete an exploration program is typically in the range of 2 to 3 years, though, for some smaller projects, it might be possible to complete the program in a slightly shorter time.

For EGS projects, the "exploration" phase is quite different from that for conventional resources, and primarily involves confirmation of temperature gradients and evaluation of the stress field and target formations for hydraulic stimulation. Assuming some temperature gradient drilling is

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geothermal development, there are several projects around the world producing geothermal power from resources of similar temperature, including one EGS project in Germany (the Landau project), where 2.5 MW of binary power are produced from an EGS doublet drilled to depths of about 10,500 feet.

EGS development requires a significant amount of water: stimulation may require several million gallons of water, and some net water loss during operation can be expected. A regional aquifer is known to exist in the Coconino-Glorieta sandstone, and a second groundwater resource in this region is contained in permeable zones between basalt flows on the eastern flanks of the White Mountain volcanic field. There may be potential conflicts for the use of water from either aquifer system.

Some of the most attractive geothermal prospects in Arizona are located within a reasonable distance from the boundaries of the Navopache service territory. Although Arizona hosts no known high temperature (>200°C) resources, there is at least one site where high reservoir temperatures could potentially exist, and several where low to moderate-temperature resources (upwards of about 120°C) may be present and extensive enough to support commercial development for power generation. These include:

1) San Francisco Peaks – This area is attractive because it offers the best potential for the discovery of a high-temperature and (possibly) extensive resource. However, substantial exploration work remains to be done, and there is no guarantee that an exploitable resource exists.

2) Clifton – This area offers an attractive combination of a known geothermal resource, relatively high temperatures, and reasonable accessibility and other logistical factors. It should be noted, however, that the cooperation of Phelps Dodge would be an important, if not essential, element of any exploration and development effort in this area.

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required, about 12 months would be required to determine project feasibility, and another 2-3 years may be required to drill and test the project wells. This timeline is longer than that for the development stage of conventional hydrothermal projects owing to the need to evaluate each well fully before drilling the next.

The overall costs of geothermal development, including both the wellfield and power plant, are presented for project sizes ranging from 5 to 50 MW. The total capital costs for a 10 MW conventional hydrothermal project is likely to be on the order of $5,500/kW. Operations and maintenance costs are likely to be on the order of $0.025 to $0.030 per kW-hour.

Based on a large body of empirical data, the total costs of conventional geothermal power are approximately 60% power plant costs, and 40% wellfield costs. A small body of empirical data suggests that these ratios are reversed in EGS development, with the wellfield costing more than the power plant. These reversed ratios have been used to estimate "base case" EGS costs, which have then been inflated by 20% to yield a "high case" EGS cost. The total capital costs for a 10 MW EGS project is likely to range from $8,500 to $10,000 per kW. Operations and maintenance costs are likely to be on the order of $0.025 per kW-hour.

For the potential EGS site in the Navopache area, an estimate of EGS development costs have been made. We assume that drilling costs for wells to 11,500 feet are likely to be on the order of $7 million per well, including stimulation. Power plant costs are likely to be on the order of $3500-$4000/kW. Assuming three wells are needed for a 5 MW project, the total costs would be on the order of $9,000/kW. This estimate would be reasonable for EGS developments of similar size and anticipated resource depth in either the Navopache or Mojave areas. Operations and maintenance costs for EGS projects are likely to be on the order of $0.025 per kW-hour.

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drilled and tested successfully to mitigate resource risk. If the project is the first one to be developed in a field, typically somewhere between 10% and 50% of the production necessary to supply the plant needs to be proven before the resource risk is acceptable the remaining development drilling to be supported by commercial project financing. In a typical project, resource risks are reduced by drilling one or two wells, studying the drilling results, siting and designing new wells based on these results, then drilling a few more wells, studying the results again before drilling the next few, and so on.

In addition, it is important to determine that injection of the waste fluid from the power plant does not pose either an operational or environmental risk. Several projects in the United States have suffered delays and a few have been damaged financially because an effective injection program could not be designed, even though the needed production capacity had been developed in a timely manner.

Even after the reservoir size and well production and injection capacities are confirmed, significant uncertainties remain regarding field development and operation, due to the inherently heterogeneous nature of a geothermal reservoir. These risks can be taken into account through the development of a range of cost estimates, and calculations of their impact on profitability. Exceeding the budget for field development, or experiencing a higher field operations and maintenance cost than expected, has not been uncommon in the industry. This risk can become a significant concern, especially in projects with high resource risk or lower-than-average projected profitability.

Another area of risk consists of environmental or permitting constraints potentially associated with a new geothermal project. A few projects (*e.g.*, Calpine's planned projects at Glass Mountain, California, where Native American issues have brought development to a halt) have been significantly delayed because of such constraints. Other projects have suffered shorter but still significant delays or have been burdened with unexpected requirements for environmental evaluation, monitoring or mitigation costs. For example, the permitting process for an expansion

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1. INTRODUCTION

1.1 Scope of Work

GeothermEx has been contracted by Black & Veatch (B&V) to evaluate the geothermal resources that may be suitable for power generation in and around the service territories of the Navopache and Mojave electric cooperatives in the state of Arizona (Figure 1.1). The scope of work for this evaluation includes:

- Literature Search. Review and evaluate the literature in the public domain and that provided by Navopache to identify and characterize known thermal waters, heat flow and geology.
- Characterize Target Areas. Using the data collected an evaluated, describe geothermal targets within or near the two service territories in terms of depth, host formations, and, if possible, order-of-magnitude estimates of generation potential.
- Evaluate Logistical Issues. For the sites identified above, make preliminary assessments of land status, access, proximity to transmission, and water availability.
- Exploration and Development Program. Develop a program of exploration and confirmation drilling, including costs and approximate time-lines.

GeothermEx has been assisted in the preparation of this report by Jim Witcher, a geologist who has significant experience with exploring and evaluating the geothermal resources of Arizona and New Mexico, and his assistance is gratefully acknowledged.

1.2 Structure of the Report

A description of the "generic" risks of geothermal resource development concludes this chapter. Chapter 2 of this report presents an overview of what is known about Arizona's conventional hydrothermal resources. The concepts for geothermal development in or around the Navopache

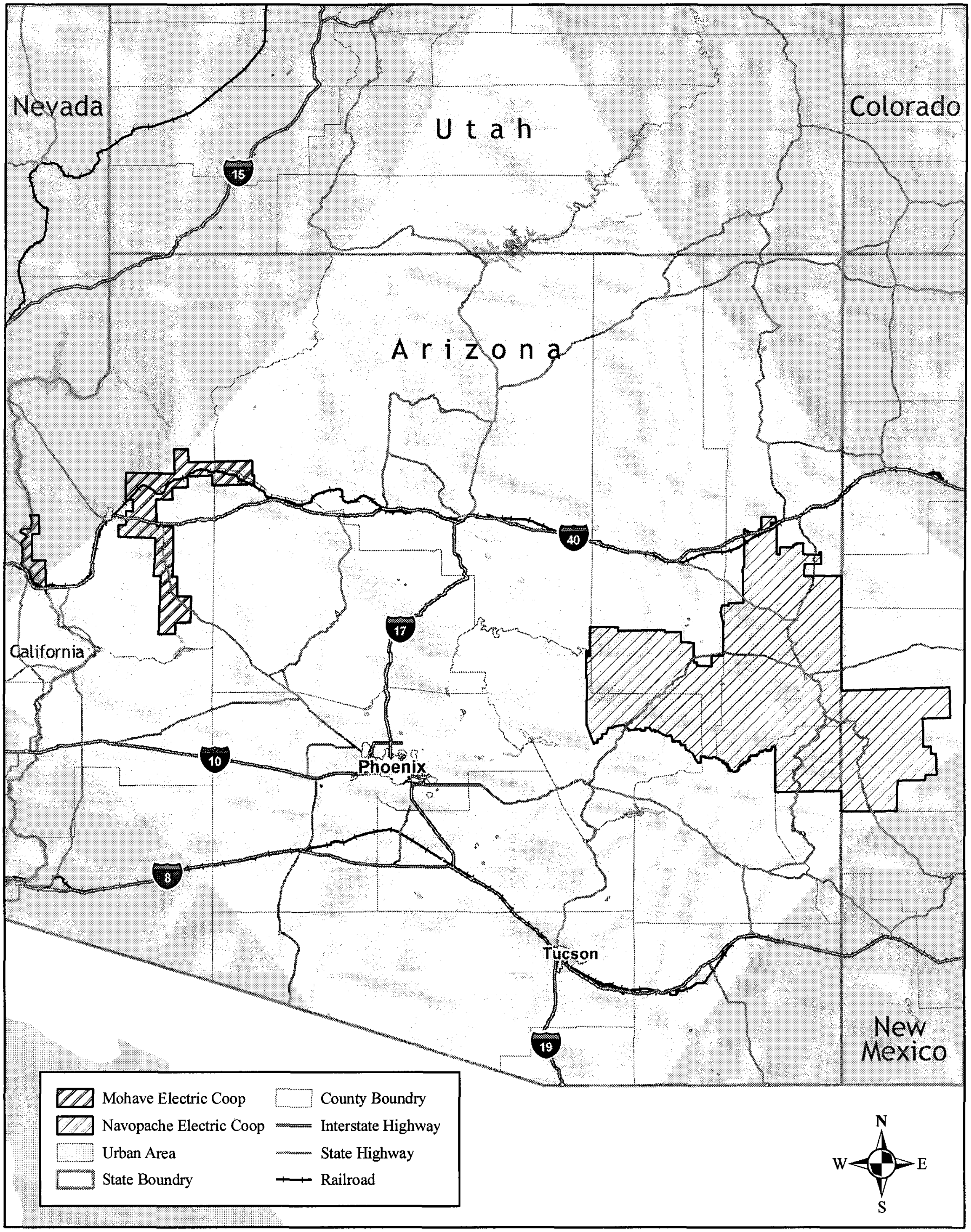

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Figure 1.1: Locations of the Navopache & Mojave Electric Coop service territories

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area are presented in Chapter 3, including EGS development. Geothermal opportunities relevant to the Mojave area are presented in Chapter 4. Summaries of the exploration and development processes and costs for conventional hydrothermal developments are provided in Chapter 5, and cited references are included in Chapter 6.

1.3 Risks in Geothermal Development

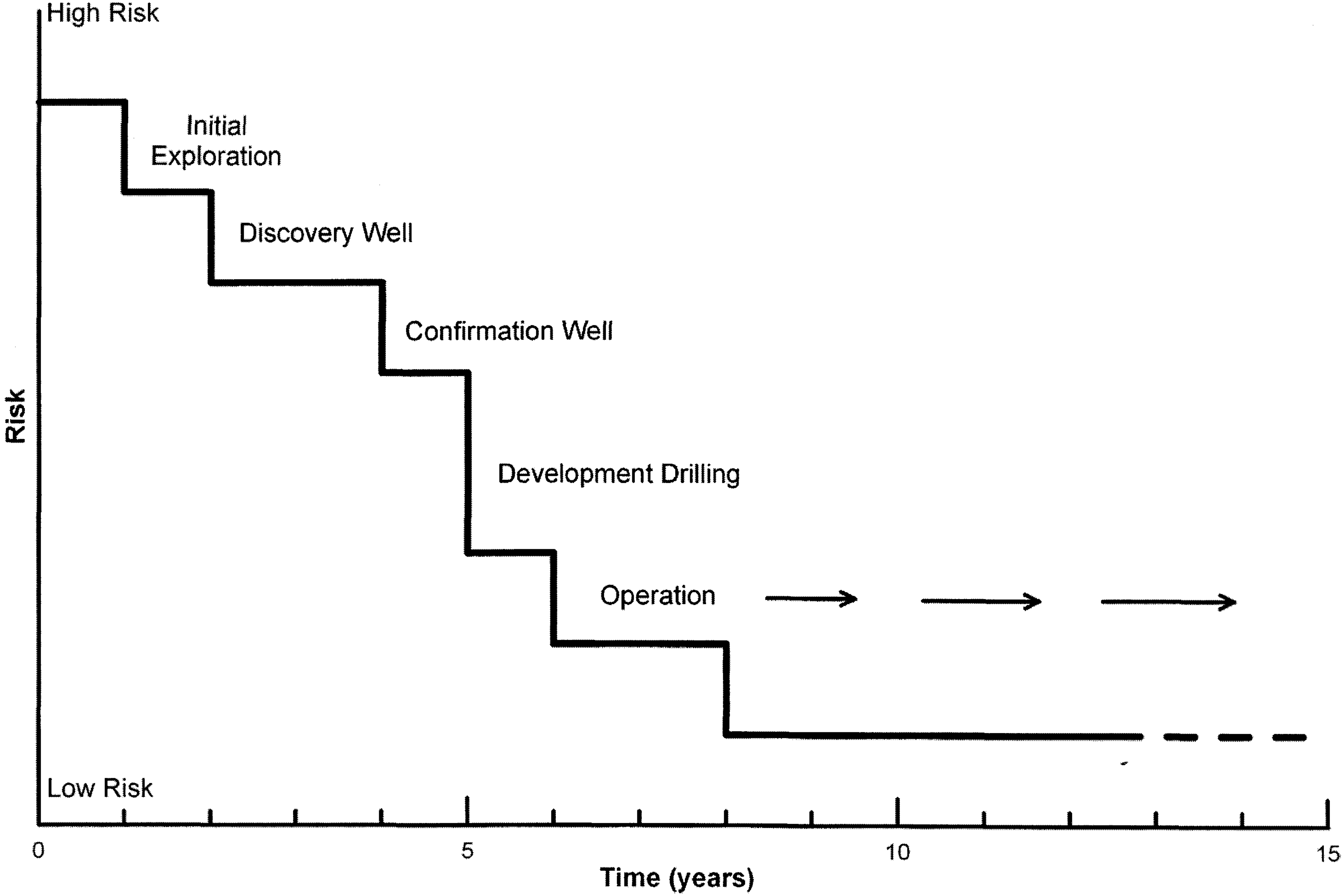
The risks that are associated with the development of a geothermal project may be divided into several categories: resource risk; market access and price risk; construction risk; organizational and management risk; legal and regulatory risk; interest and inflation rate risk; and *force majeure*. We focus herein mainly on resource risk, which we feel is the single biggest risk that must be considered, particularly at the stage of project identification and exploration.

1.3.1 Conventional Hydrothermal Projects

The first resource risk confronting a geothermal project, during the exploration or initial drilling stage, is whether or not a commercial geothermal reservoir exists in the project area; the resource risk is at its highest at this stage. As shown in Figure 1.2, until exploration (including drilling and initial well testing) has confirmed the existence of a commercial resource, the risk is at a maximum. Therefore, partners are sometimes sought during the exploration and initial drilling phase, using some combination of equity contribution, corporate funds, corporate loans and public power revenue bond issues, depending upon project ownership.

Even after a commercially attractive resource is discovered, the size of the reservoir and the ability of the future wells to deliver geothermal fluids at commercial rates are not known with certainty. These perceived risks regarding reservoir size and deliverability may discourage investment and/or financing until a sufficient number of wells have been drilled and tested to demonstrate that: 1) the available reserves are adequate for the contemplated project; and 2) the wells will produce at commercial rates. If a successful commercial project already exists in an adjoining leasehold in the same field, typically only one or two "step-out" wells need to be

Figure 1.2: Schematic representation of resource risk in a typical geothermal project



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of the generation capacity from 12.5 MW to 42.5 MW at the Long Valley geothermal field in California proved to be a major hurdle. As a condition of the permit, the developer had to commit funds to monitor, for the entire plant life, any potential impact of the increased production and injection on the local ground water system, and in particular on the spring supplying fluid to a local fish hatchery. In some projects, unexpected environmental issues have arisen after the field has already been developed and power generation has started. For these reasons, assessing environmental and permitting risks associated with the resource not only prior to or during field development, but also subsequently during power plant operation, is critically important to risk mitigation.

Finally, one must consider the risk of resource degradation. Most geothermal reservoirs degrade in some way as a consequence of production and injection. For example, the production wells in a geothermal project may decline in production rate and/or temperature (or enthalpy), or the injection pressure may increase unduly, or the chemistry of the produced fluid may change adversely with time as the project is operated. All of these have been experienced in various geothermal projects in the United States. The possibility that the capital invested in a geothermal power plant and well field may become unrecoverable should the resource degrade prematurely is troubling to financial institutions and utilities alike.

Once a resource has been found and tested, the risk of undue degradation must be evaluated. Quantification of this risk and an estimation of its cost consequence are theoretically possible, utilizing the predictive capability of numerical modeling. One can model on the computer the physical and/or chemical processes in the reservoir and/or well-bores in consequence of production and injection. However, forecasts from numerical reservoir modeling are most reliable when the model is calibrated against a reasonable period of production/injection history; the longer the available history, the more reliable the calibration. In some cases, such models are calibrated only against data collected during well tests of perhaps a few weeks to a few months in duration. With such short calibration periods, the forecasts from these models may have substantial uncertainties of their own adding, to the natural uncertainty of reservoir performance.

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Numerical reservoir modeling has proven valuable in assessing the risk of resource degradation prior to undertaking capacity expansions at existing projects, the production/injection history of the original project usually providing adequate data for model calibration. A typical example of this situation comes from the Salton Sea, East Mesa and Heber geothermal fields in California, and the Steamboat field in Nevada, where several plants were financed and built in succession, each phase of the project providing calibration data for the modeling of the next phase of reservoir development.

These resource risks can be impacted (favorably or otherwise) by technological developments, changes in demand for electric power or in energy cost, government policies on energy, pricing, taxation or environment, and *force majeure*. That is, risks other than questions of the existence of the resource, its overall quality and how it will respond to exploitation, can change in perception or in reality over time. For example, a major hurdle in the development of the Salton Sea field in California was the perceived risk of in handling the hypersaline brine (about 8 times the salinity of sea water). A small experimental fluid handling facility was operated at Salton Sea in the early 1980s to investigate the fluid handling problems. A 10 MW demonstration project was subsequently operated in the Brawley field (also containing hypersaline brine) for several years to prove the necessary fluid handling technology. These demonstration projects facilitated the development of the commercial technology for the handling of hypersaline brine and sharply reduced the perceived technological risk. Several power plants (totaling more than 300 MW) have been brought on line in this field, each plant helping to further reduce the perception of the fluid handling risk. Today this risk is no longer an important consideration in developing the resource at Salton Sea, and more capacity expansions are planned. Similarly, development of binary cycle technology has helped to change the definition of commercial geothermal resource, such that fields with temperatures considerably lower than 150°C have now become developable commercially, at acceptable levels of risk. Less than 20 years ago, such resources would have been considered non-commercial for power generation.

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Many approaches have been tried in the United States to mitigate resource risk in geothermal projects, with varying success. Mitigation can be achieved through some combination of:

- Ensuring that the field has been adequately explored before development plans are made.
- Careful selection of projects, with close attention to the prior experience and technical and management skills of the developer.
- Careful, independent review of the development plans to remove any optimistic bias in the plans, or any intentional or accidental downplaying of the risks.
- Stringent examination of the development and operational plans for the "worst-case" scenario.
- Requirement of rapid and effective response to environmental, permitting and other regulatory issues related to field development that could impact upon development practice, timetable and cost. The potential adverse effects of environmental constraints on a project typically are built into the worst-case scenario.
- Design and implementation of a program of "milestones" relating to field development objectives and timetable.
- Conscientious use of numerical modeling to track well deliverability, resource quality and reservoir response, and to forecast reservoir and well responses under various production and injection scenarios.
- Routine milestone review meetings, with mechanisms for ownership transfer or shutdown of the project in event of failure to satisfy milestone objectives. Salvage operations may also be designed as part of the worst-case scenario.

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In addition to the risks outlined above, in Arizona it is prudent to evaluate the availability of water for drilling operations, and, more significantly, for cooling water during routine power plant operation. It is likely that the drilling water needs can be resolved because they are temporary, but the availability of water for power plant cooling poses a significant risk. This is particularly important in the Mojave Coop area, since ambient temperatures are highest during the summer, when demand is also highest. The laws of thermodynamics dictate that the available work increases with the available temperature differential between the resource and the medium used for cooling. For this reason, the output of air-cooled power plants varies significantly with ambient air temperature. If water is available for cooling, the reduction in output during the summer months can be minimized. Considering that the temperatures of Arizona's resources are relatively modest, water-based cooling would lessen seasonal output variations and improve the economics of development in the lower-elevation parts of the State.

1.3.2 Additional Risks in EGS Projects

Conventional hydrothermal resources exist because of the convergence between high temperatures and good permeability. Circulation of hot waters over geologic time can create significant hydrothermal resources that can be tapped directly by drilling. In Enhanced Geothermal System (or EGS) projects, permeability must be enhanced, typically by hydraulic stimulation. EGS risks include all the items discussed above, but there is an additional, important risk: the creating a large enough and complex enough heat exchanger in the subsurface.

At present, there is only geothermal power project in operation that has used EGS techniques to enhance reservoir permeability: the 2.5 MW Landau project in Germany. This project targets a faulted and fractured sandstone reservoir zone at depths of about 3,250m (~10,500 feet), and temperatures of about 150°C. Water is circulated in a production-injection doublet. The production well encountered good natural permeability, but the injection well was relatively tight and was hydraulically stimulated to increase its injectivity; therefore, one may consider Landau

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to represent half of an EGS project. Nevertheless, it remains the only operating geothermal project that used hydraulic stimulation to increase permeability (a ~1 MW EGS demonstration project may start operating in Australia in 2009).

This limited body of experience with EGS technology adds a layer of resource risk to the geothermal project in that hydraulic stimulation may not yield the desired combination of fluid flow and heat transfer. For example, an over-stimulated well may result in too direct a flow path between production and injection wells, leading to rapid cooling. Alternatively, an under-stimulated well may require unduly high pressure on the injection side, and limited productivity on the production side. Multiple stimulations may be required to achieve optimum results, adding to resource development costs.

Furthermore, there is no body of experience with the long-term behavior of EGS developments, which may be affected by continued thermal contraction (further enhancing permeability), mineral precipitation (which would reduce permeability) and mineral dissolution (enhancing permeability). These risks add to those presented above for conventional hydrothermal resources.

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2. CONVENTIONAL HYDROTHERMAL RESOURCES IN ARIZONA

2.1 Introduction

Although there has been little commercial development of geothermal resources in Arizona, and none for electrical power generation, the occurrence of potential resource areas, particularly as indicated by surface manifestations of thermal activity, has been investigated quite thoroughly by previous investigators. A detailed compilation of the most important thermal manifestations, along with an evaluation of the regions of greatest potential, was made and presented in the form of a state geothermal resource map by Witcher *et al.* (1982). This document gives locations and descriptions of several hundred warm to hot springs and wells that occur within the state, and shows the zones considered to be most favorable for geothermal exploration on the basis of the surface indications and interpretation of geologic setting, hydrology and other conditions. Most of the geothermal manifestations in Arizona are found within the physiographic province known as the Transitional Zone, and the parts of the Basin and Range Province that are close to the Transitional Zone (Figure 2.1); however, some indicators of geothermal activity occur within virtually all parts of the state, including the Colorado Plateau province.

The compilation of Witcher *et al.* (1982) and more site-specific or region-specific studies were reviewed as the initial step in identifying the geothermal prospects in Arizona that may be most suitable for electrical power generation. From the known or inferred occurrences of geothermal activity, the most attractive resources in Arizona can be identified using the following characteristics (listed in roughly descending order of importance):

- anticipated resource temperature;
- potential extent of the resource;
- other technical factors affecting the feasibility of development; and
- non-technical factors affecting the feasibility of development.

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Some comments on each of these factors follow.

2.2 Resource Temperature

Surface manifestations of thermal activity (hot springs, warm springs, fumaroles, etc.) provide a strong but somewhat indirect indication of the presence of subsurface geothermal activity. In many (but not all) cases, higher-temperature surface waters are indicative of higher subsurface temperatures, but, since spring temperatures are limited to the boiling point at the corresponding surface elevation, there is a limit to how good a guide springs can be to subsurface conditions.

Subsurface temperatures must therefore be determined either:

- directly, if wells or other drillholes have been drilled to a sufficient depth to adequately measure temperatures at the subsurface zones of interest; or
- indirectly, by calculation of chemical geothermometer temperatures from chemical analysis of samples water or steam.

Chemical geothermometers serve as indicators of the deep equilibration temperatures of geothermal fluids that leak to the surface, because of the tendency of chemical reactions to slow down markedly as temperatures decrease. Concentrations or ratios of certain chemical constituents of fluids that are "set" at higher temperatures can be preserved as the fluids cool while they ascend to the surface. The most common geothermometers applied to geothermal waters are based on silica concentrations, and on the ratios of cations such as sodium, potassium, calcium and magnesium.

The application of chemical geothermometry is subject to limitations, because the chemical relationships on which the geothermometers depend can be affected by re-equilibration, mixing with other fluids, and other phenomena. Nevertheless, the method has proven to be quite successful in predicting subsurface temperatures in a general way, particularly when several different geothermometers agree and the results are properly interpreted in the context of the

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overall composition of the geothermal fluids and the geologic environment in which the manifestations occur.

Chemical geothermometers from the various sites of thermal manifestations in Arizona were reviewed and evaluated to identify the localities where resource temperatures may be adequate to support electrical generation. For this purpose, the practical cut-off temperature is about 250°F (120°C), because below this temperature the efficiency of power conversion decreases rapidly, but lower temperatures may be considered in certain situations. Where temperature data were available from drillholes, this information was used to determine or extrapolate potential resource temperatures.

2.3 Resource Extent

Until several deep wells have been drilled in a prospect area, it is generally not possible to determine the extent of a geothermal resource with any degree of precision. However, it is possible to estimate the potential extent from indirect indicators such as the number and distribution of thermal manifestations, results of surface exploration work (such as geophysical surveys), and interpretation of subsurface geologic conditions from surface mapping. This process is necessarily subjective, and must be based on experience to some degree (taking into account the characteristics of developed geothermal systems in similar settings).

2.4 Other Technical Factors

In addition to the important criteria of resource temperature and extent, several other technical characteristics of a geothermal resource can affect the feasibility of its economic development for power generation. These include:

- the depth to the resource (which will affect drilling and therefore development costs);
- the chemical characteristics of the geothermal fluids (which may affect development and operating costs if they have a tendency to cause scaling or corrosion); and

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- the productivity of wells drilled to exploit the resource.

All of these factors are difficult, if not impossible, to evaluate adequately in the absence of direct data from exploratory or development wells. However, in some cases some inferences about them can be made from geologic data or from knowledge of similar geothermal systems in comparable settings.

2.5 Non-Technical Factors

Various non-technical factors can affect the feasibility of development of a geothermal resource. These include:

- access to the area, whether by existing roads or by roads that can be constructed economically;
- terrain conditions, particularly as regards the feasibility of constructing and accessing sites for drilling over a sufficiently broad area to support a development;
- proximity to transmission lines with available capacity;
- availability of water for drilling and cooling;
- existing land uses that might conflict with geothermal development; and
- environmental restrictions or other regulatory factors that could restrict, constrain or slow the pace of development.

Comments on the various non-technical factors that could affect development at the selected sites are included within the area-by-area descriptions in subsequent chapters.

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3. RESOURCE POTENTIAL IN THE NAVOPACHE COOP AREA

3.1 Introduction

As can be seen in Figure 2.1, the known or suspected conventional hydrothermal resource areas in Arizona are largely found outside the Navopache service territory. The three hot spring areas in the eastern part of the Navopache area are unlikely to be prospective for geothermal development, as will be described in a later section of this report. However, it may be possible for electricity generated from conventional geothermal resources to be brought into the Navopache area, and EGS development within the Navopache may be considered.

3.2 Geology

As shown on Figure 2.1, the Navopache service area occupies the transition between the Colorado Plateau Province and the so-called "Transition Zone" of the Basin and Range Province the south. Geologically recent (Pleistocene to Holocene) movement has occurred on several major and reactivated faults zones in the area. The southwestern margin of the Colorado Plateau also has high elevation compared to the Colorado Plateau interior and is demarcated from the Basin and Range on the south by the Mogollon Rim, a major topographic escarpment that originated in Oligocene time (about 26 to 28 million years ago, or "Ma") (Peirce *et al.*, 1979). Prior to the Oligocene, the Colorado Plateau was at a lower elevation than terrain to the south and was traversed by north-flowing drainage. Important uplift has occurred in the region in the last 4 to 6 Ma (Karlstrom *et al.*, 2008).

Several geologic features have an important bearing on the subsurface thermal regime and hydrogeology of the area. The regional tectonic setting is demonstratively favorable for magma generation in the mantle, as evidenced by the presence of several large Neogene (Recent to late Miocene) volcanic centers, including the Springerville, White Mountain and Red Hill-Quemado volcanic fields. As shown in Figure 3.1, age-dating of volcanic rocks has shown that the volcanism in these fields is relatively young, ranging in age from less than 0.5 to 10 Ma. The

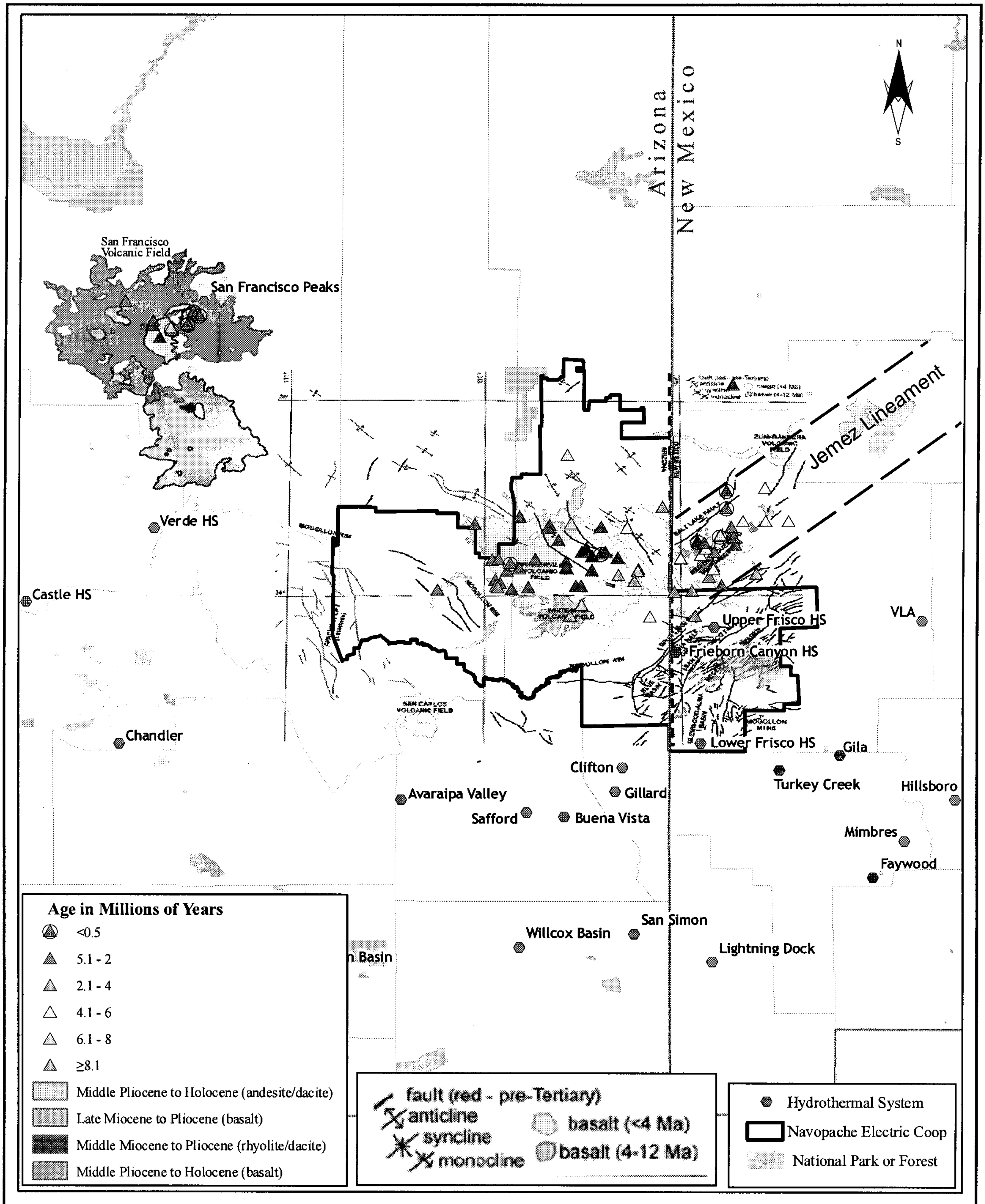

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Figure 3.1: Tectonic map showing age dates of young volcanic rocks, Navopache Electric Coop area

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dominant volcanic rock type is basalt, which has low viscosity and a relatively short "residence" time in the crust. However, episodic basaltic volcanism can, over time, cause a heat flow anomaly and possible provide a heat source for geothermal resources. The island settings of Hawaii and Iceland certainly provide evidence of geothermal potential in basaltic terranes; however, most of the major high-temperature geothermal fields around the world are associated with more silicic volcanism, which tends to create a larger heat flow anomaly owing to longer crustal residence times.

The geologic sequence in the central part of the Navopache area has been informed by the Alpine 1 core hole, a fully cored well drilled to 4,505 feet in 1993 (Witcher *et al.*, 1994). Alpine 1 is located on the eastern side of the White Mountains, near the intersection between the White Mountains and the ENE-trending Jemez volcanic lineament, a regional geologic feature that extends into neighboring New Mexico (Figure 3.1).

Tertiary sedimentary and volcano-sedimentary units overlie upper Cretaceous sedimentary rocks, beneath which a regional unconformity separates the Cretaceous rocks from the Permian San Andres (Kaibab), Glorieta (Coconino) and Supai Group. The upper part of the San Andres (Kaibab) Formation is missing in this location. Several basaltic sills and dikes intruded into the Permian section, and several thin Eocene to Oligocene ash-flow and air-fall tuff units are interbedded in the Tertiary sedimentary section. The top of the Precambrian granitic basement rock is anticipated to lie at about 5,700 feet beneath Alpine Divide. A generalized cross section through the area from Nutrioso to Alpine is presented in Figure 3.2.

3.3 Thermal Springs and Wells

Numerous thermal wells and springs are found in the area, as shown in Figure 3.3. These have quite modest measured temperatures (up to perhaps 70°C), but some have hotter "source" temperatures (*i.e.*, inferred reservoir temperatures) that have been estimated using geothermometry based on the chemical composition of the sampled waters. The temperatures

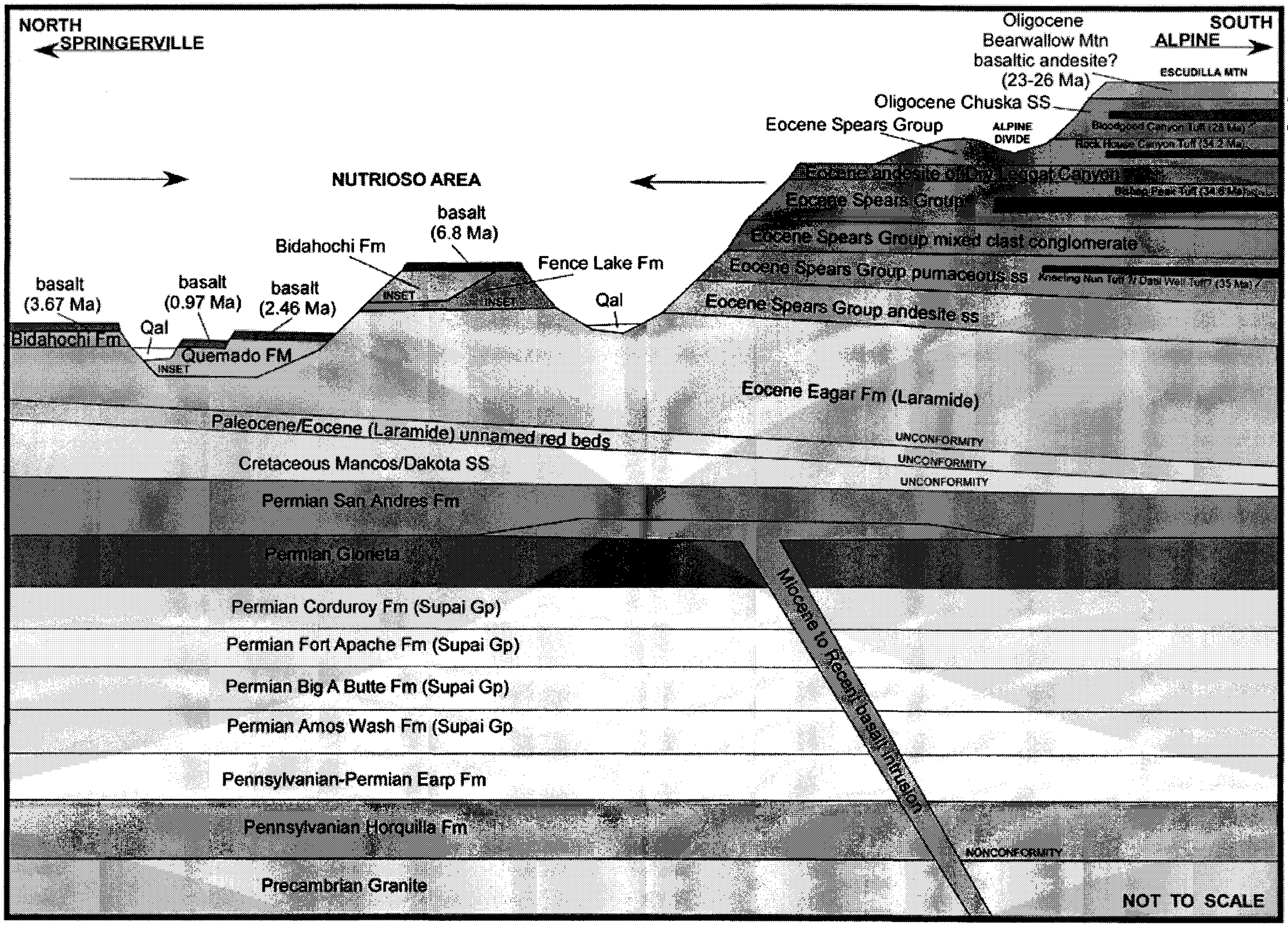

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Figure 3.2: Generalized geologic cross section, Nutrioso-Alpine area

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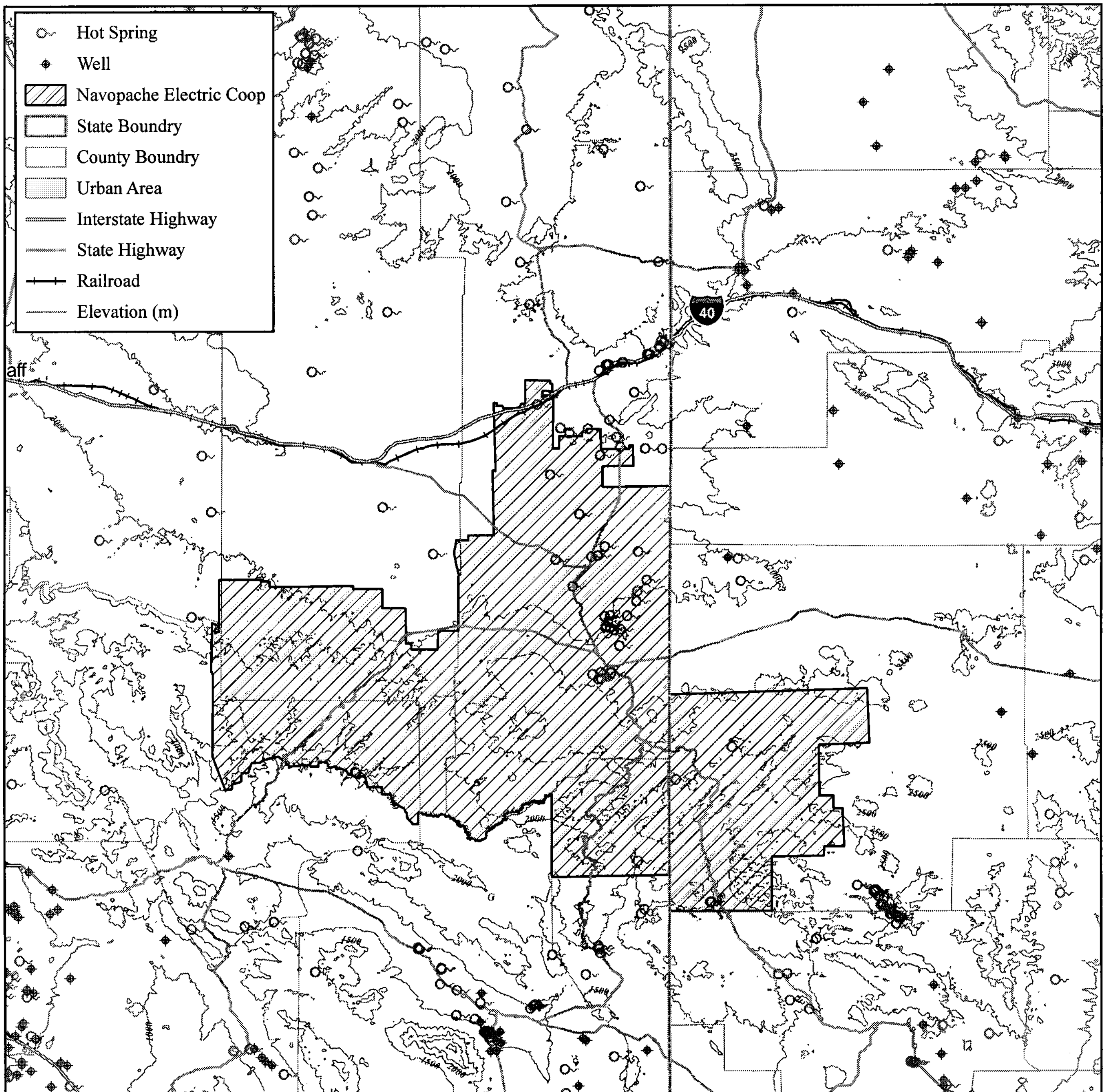

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Figure 3.3: Locations of thermal wells & springs, Navopache Coop area

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estimated using the sodium-potassium-calcium (Na-K-Ca) geothermometer are shown for the Navopache area and surrounds in Figure 3.4. The geothermometer temperatures cover a wide range, from near sampling temperature to a maximum of about 160°C. The data were contoured in an attempt to determine if estimated resource temperatures show a pattern: none was anticipated and none was found, other than the presence of high temperatures around the known hydrothermal resources at Gillard and Clifton (and an indication that the nearby Lower Frisco Hot Springs may also have favorable temperatures), a broad area east of the eastern border of the Navopache area in New Mexico, between the fields marked VLA (in the Augustin Valley, home to the "Very Large Array" radio telescope) and Hillsboro, and the area around the Lightning Dock field in the SW corner of New Mexico.

As will be discussed below, Clifton is one of the most prospective geothermal resource areas in Arizona. The geothermometry at the VLA site may be influenced by the playa geology of the area, but this remains to be evaluated. The Hillsboro Hot Springs appear to represent an attractive area for geothermal exploration. The Lower Frisco Hot Springs probably represents the only conventional hydrothermal target area within the Navopache service territory.

Geothermometry does not suggest high resource temperatures in the Upper Frisco and Freiborn Hot Spring areas, all of which are located in the eastern part of the Navopache service territory.

3.4 Heat Flow

Heat flow data have been estimated from measured temperatures in wells across the area, including some relatively deep hydrocarbon exploration wells and of course the Alpine 1 core hole. These data are presented in Figure 3.5, and show high heat flow in four areas: 1) in the northern part of the Navopache area; 2) to the NE of the Alpine 1 core hole; 3) S of the Navopache area (between Buena Vista and Avaraipa Valley); and 4) along the eastern boundary of the map in New Mexico. There is also a suggestion of higher heat flow in the SE corner of the Navopache area, in the region of Lower Frisco Hot Springs. These elevated values of heat flow

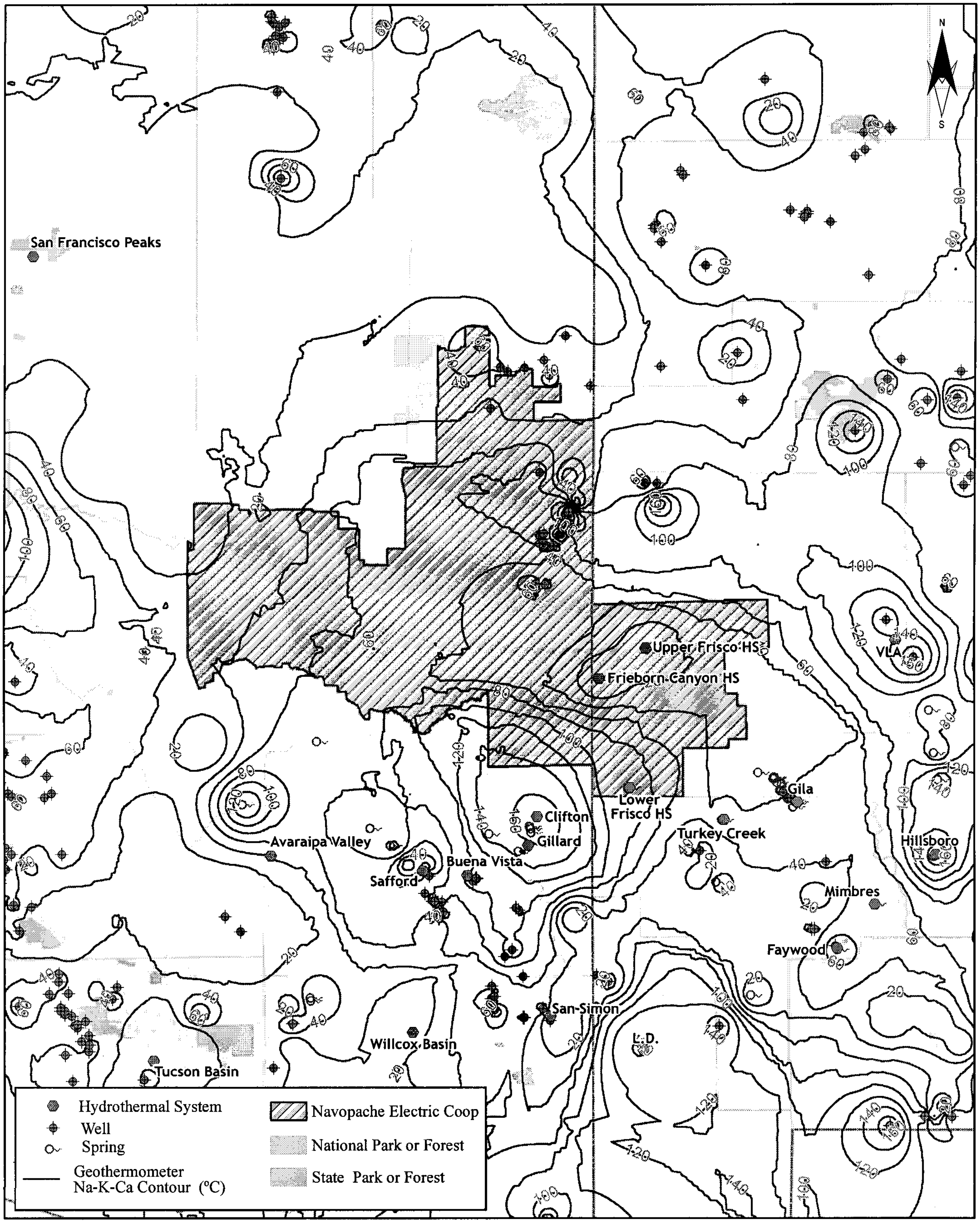

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Figure 3.4: Na-K-Ca geothermometer temperatures from thermal wells and springs, Navopache Electric Coop area

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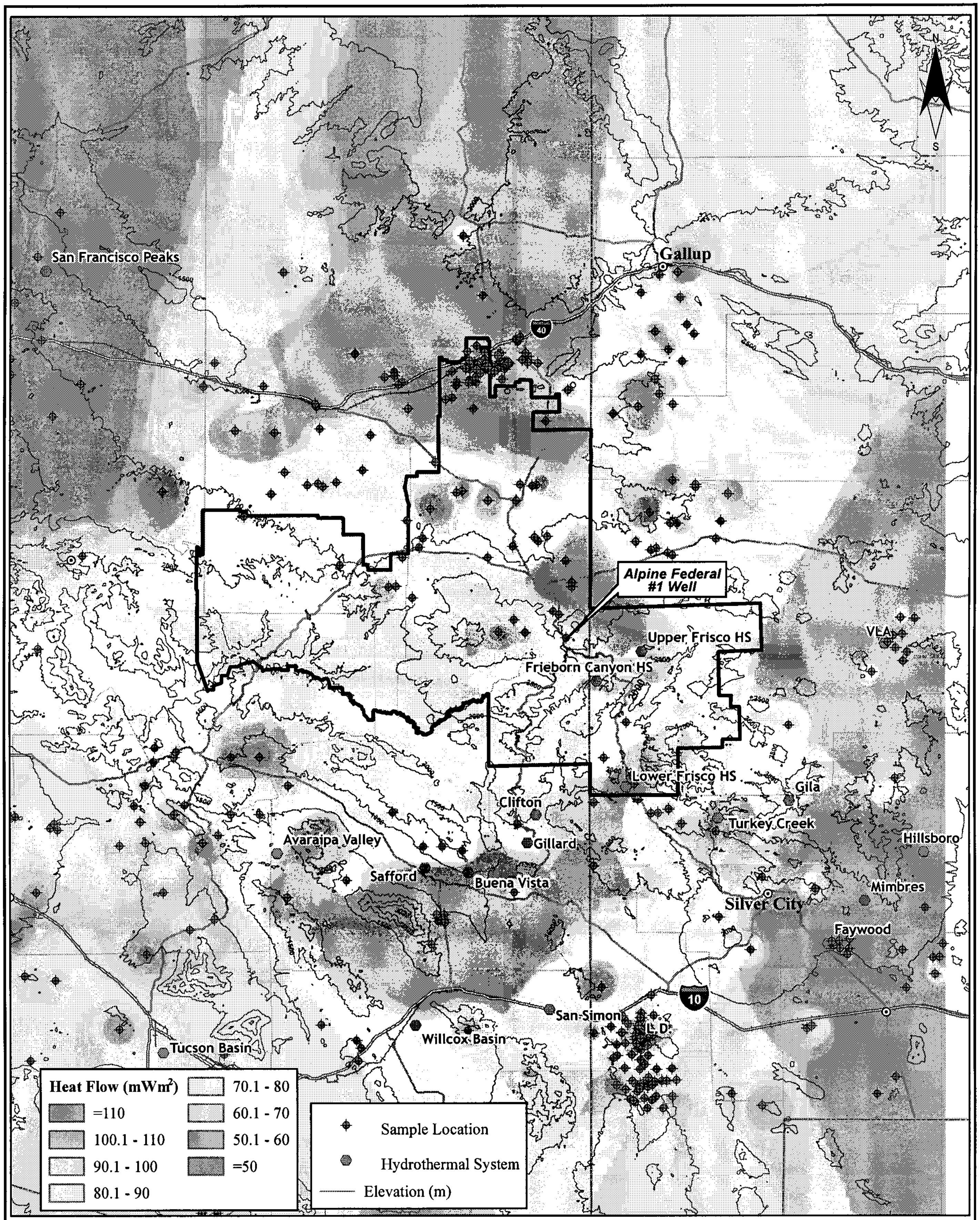

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Figure 3.5: Heat flow map, Navopache Coop area

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are more typical of the Basin and Range rather than the lower heat flow observed in the Colorado Plateau (Minier and Reiter 1991; Reiter *et al.*, 1975; Sass *et al.*, 1982; and Witcher *et al.*, 1994). Interestingly, the San Francisco Peaks are shows relatively low heat flow, despite the presence of young (<0.5 Ma) silicic volcanic rocks. This is thought to be due to groundwater infiltration, which is masking the heat flow observed in the shallow wells drilled in this area.

Regional background heat flow of the southern Colorado Plateau is around 65 mW/m^2 (Minier and Reiter, 1991) with localized areas in excess of 90 to 100 mW/m^2, as demonstrated by the anomalies in and around the Navopache area. Anomalous heat flow in excess 100 mW/m^2 requires explanation. Neogene volcanism with magma intrusion and high radiogenic heat production in the upper crust are potential processes. Regional areas of higher heat flow between 65 and 80 mW/m^2 on the Colorado Plateau margin may be the result of deep heating in the upper mantle associated with Oligocene to present day Basin and Range extension and the mid-Tertiary Mogollon-Datil volcanic field (Minier and Reiter, 1991). The large Mogollon-Datil volcanic field in the Transition Zone (to the south of the Neogene Springerville, White Mountain and Red Hill-Quemado volcanic fields) contains several large rhyolite caldera complexes and is probably underlain by a mid-Tertiary granitic body. Residual heat from this older (yet intense) thermal feature has probably contributed to the higher observed heat flow along the southern periphery of the Colorado Plateau.

The area of high heat flow in the northern part of the Navopache area occurs over and adjacent to the Pinta Dome, a geologic structure on the northern margin of the Holbrook basin near Sanders and I-40. The Pinta Dome area is known for some of the richest helium-bearing gas wells ever produced. The helium may provide an explanation for the high heat flow (>100 mW/m^2) in the area. Two sources of helium are possible. One source is primordial helium originating in the mantle more that 40 to 50 km beneath the region. In this case, primordial mantle helium would be entrained with other fluids (such as magma and CO_2) that are convectively transporting significant heat to the shallow crust. The young volcanism and CO_2-rich springs with associated travertine spring deposits in the region are consistent with this model of higher heat flow. Heat

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and helium gas are also created through the decay of uranium. A large deep-seated Precambrian granite body that has high uranium mineral concentrations would provide the other potential mechanism for high heat flow and helium in the Pinta Dome area. When uranium decays, it also generates heat. Nearly all atmospheric helium is ^{4}He. However, the deep interior of the earth has elevated ^{3}He or primordial helium. Radioactive decay of uranium in the crust creates ^{4}He or radiogenic helium. An analysis of the ratio of the helium isotopes ($^{3}He/^{4}He$) would provide valuable information to understand the relative importance of both processes in creating the higher heat flow to the north of the Navopache area.

The second and third areas of high heat flow are just northeast of the Alpine 1 core hole and east of Nutrioso and northeastward into New Mexico. This area may also have an enhanced radiogenic heat component from decay of uranium in Precambrian granite. However, the areas also occur adjacent and on a northeast trending zone of older (4 to 6 Ma) basalt intrusions and flows that extends northeastward into NM. This northeast trending zone is coincident with the Jemez Zone or Jemez Lineament (see Figure 3.1), a large regional trend of young volcanism that may be easily traced from San Carlos, Arizona to Raton, New Mexico. The cause this linear trend is not completely understood, except that in generally coincides with the tectonic boundaries between the Colorado Plateau, Basin and Range and Rio Grande Rift, where crustal stress regimes and directions seem to change. The zone may also represent a major boundary in the crust created in Precambrian during accretion of elements of the North American continental crust.

The broad area of higher heat flow in the eastern part of the mapped area in Figure 3.5 is related to thermal processes associated with the Rio Grande Rift, a region characterized by high heat flow, young volcanism and faulting.

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3.5 Geothermal Potential Within the Navopache Service Territory

3.5.1 Conventional Hydrothermal Development

There is one obvious indication of potentially exploitable conventional hydrothermal systems exist within the Navopache area: the Lower Frisco Hot Springs or San Francisco Hot Springs area near Glenwood. This hot spring system, formerly designated as a Known Geothermal Resource Area (KGRA), may offer an attractive prospect for small-scale power production with binary technology from a hydrothermal system.

The Lower Frisco Hot Springs range in temperature from 30 to 49°C and discharge sodium-chloride water with total dissolved solids up to 1,300 mg/l in the bottom and along the banks of the San Francisco River for more than 1,500 feet. The thermal waters show a range in chemistry that indicates mixing and may have a significant cumulative discharge rate. The silica (quartz) geothermometer is 132°C and the Na/K/Ca geothermometer is 148°C for the hottest sampled discharge site on the banks of the San Francisco River. The magnesium concentration seems too high for a reliable Na/K/Ca geothermometer and suggests near surface-chemical interaction of cooled geothermal fluids with basalt and andesite.

Spring discharge occurs near the location where the San Francisco River makes a sharp turn to the west into volcanic bedrock out of the alluvium filled Glenwood-Alma basin, a north-south oriented Neogene graben complex that connects the west-northwest striking Mangas half-graben to the southeast with the northeast-striking Reserve half-graben to the north (these features are shown in Figure 3.1). Prior to late Pliocene the San Francisco River discharged into a large closed-basin lake in the Mangas half-graben before entrenching an impressive canyon to Clifton, Arizona to the west and the Gila River.

The area probably overlies the ring fracture zone of a deeply-buried large ignimbrite cauldron of Eocene age that erupted the Cooney tuff observed at Clifton, Arizona and White Water Canyon of the Mogollon Mountains northeast of Glenwood. The White Water Canyon outcrops are

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interpreted as cauldron facies ash flow tuff (filling the caldera collapse crater) while the Clifton exposures are outflow facies (deposited more distally from the source). A series of mostly older NE-trending faults and grabens in mid-Tertiary volcanics (mostly basaltic andesite) connects the Lower Frisco Hot Springs with the Clifton area. Quaternary faulting is observed in the Glenwood-Alma basin, especially along the base of the Mogollon Mountain.

The Lower Frisco Hot Springs are poorly characterized; but the moderate geothermometers for mixed waters, potentially large natural discharge rate, favorable structure and hydrogeologic setting, and chemical similarity to Clifton Hot Springs make the area an attractive geothermal prospect.

3.5.2 EGS Development

Considering the limited opportunities for conventional hydrothermal development, EGS is another option that may be considered for a small geothermal project within the service territory. As discussed above, EGS remains in the realm of experimentation and demonstration; however, there is a growing realization that if geothermal is going to provide a significantly larger fraction of the world's energy than it does today, EGS will play a significant part. There is an abundance of heat everywhere in the earth's crust, albeit sometimes at great depth. This heat can be extracted by circulating water through hot rocks in which permeability has been enhanced enough to create the underground heat exchanger that nature did not provide.

Permeability enhancement in EGS development is made by pumping cold water under pressure into an EGS well. The idea is not to create new tensile cracks in the rock (as is typically done when hydro-fracturing hydrocarbon wells) but to increase pore pressure in the rock mass to the point where certain pre-existing fractures to fail in shear mode. The pre-existing features that will be easiest to shear will be those that are optimally oriented with respect to the current-day stress field. Based on data from the World Stress Map (Heidbach *et al.*, 2008), the direction of maximum horizontal stress in much of the Navopache appears to be oriented WNW, which is the

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likely direction of reservoir growth as fractures open upon increases in pore pressure. However, analysis of cinder cone alignment in the Springerville volcanic field suggests that the direction of maximum horizontal (compressive) stress changes from WNW in the western part of the field to ENE in the eastern part of the field (Connor *et al.*, 1992). This change is consistent with the change in strike direction of the southern boundary of the Colorado Plateau, from the WNW in most of Arizona to ENE near the border of New Mexico and in New Mexico itself (see the Datil-Mogollon section of the Transition Zone in Figure 2.1). Further, the crust of the Colorado Plateau E of the White Mountains is depressed (due to loading with Tertiary volcaniclastic sediments shed from the Mogollon-Datil volcanic field), forming a S-sloping Precambrian basement that is referred to as the Mogollon Slope. W of the White Mountains, the Precambrian basement dips to the north, into the Colorado Plateau, forming the Mogollon Rim. This change also suggests a regional change in stress direction, and it will be important to understand the stress field in the context of an EGS project.

Navopache could consider developing either a doublet (1 producer 1 injector) or a triplet (central injector flanked by 2 producers) to develop something on the order of 5 MW of power. As indicated in maps provided by Navopache, some land may be available for this type of development (see Figure 3.6).

As shown in Figure 3.7, data from the Alpine 1 core hole suggest that temperatures of 300°F should be reached by 10,000 feet. While this is relatively modest temperature for geothermal development, there are several projects around the world producing geothermal power from resources of similar temperature, including one EGS project in Germany, which is a remarkably close analogue to the Nutrioso-Alpine area in that similar temperatures are reached at 11,500 feet. This is the Landau project, where 2.5 MW of binary power are produced from an EGS doublet of wells drilled to about 3,250m.

The top of the Precambrian basement rock is anticipated to be encountered at an elevation of +2,850 feet (msl), which is quite deep. Data from other wells in the region show that the top of

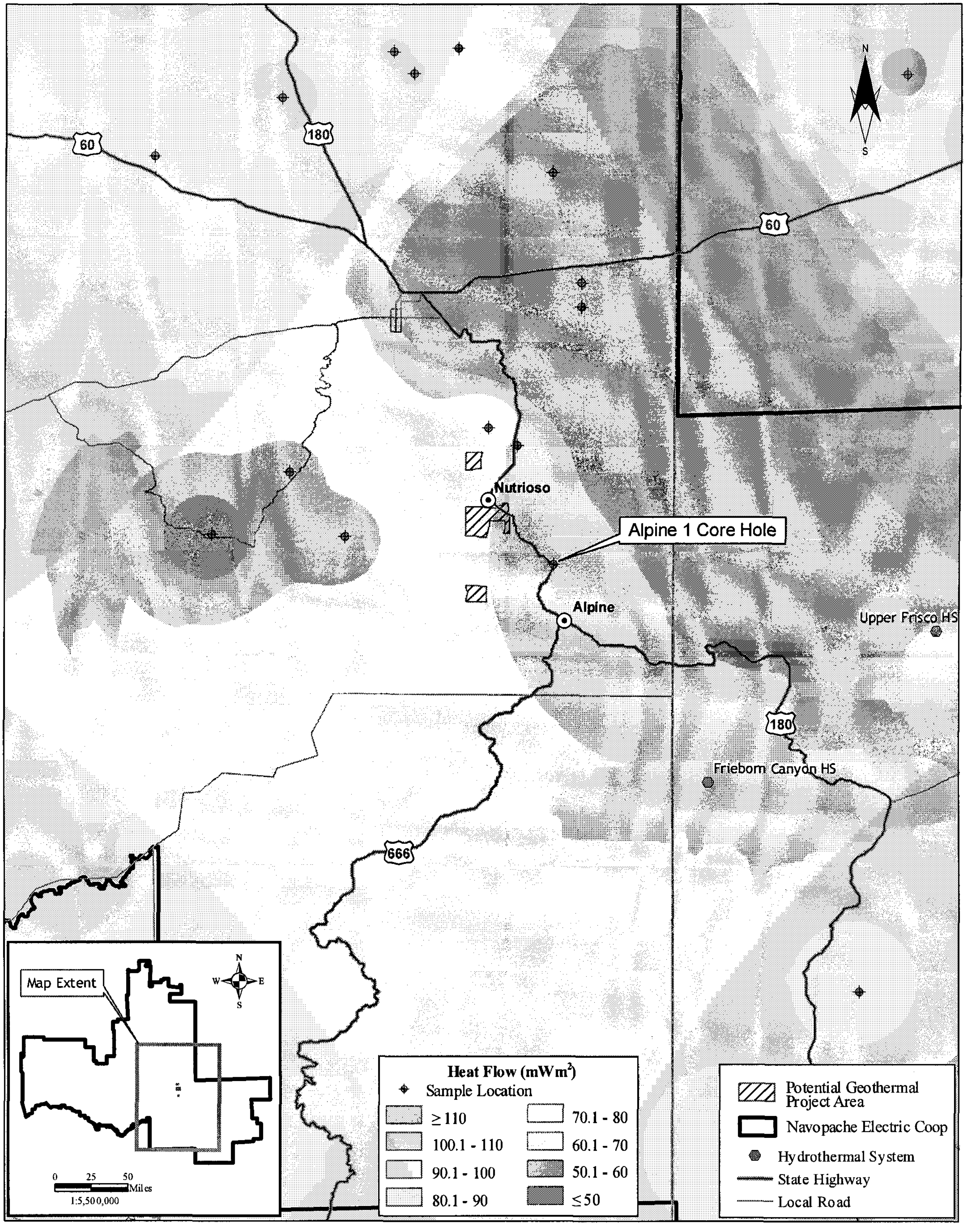

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Figure 3.6: Lands potentially available for geothermal development in the Navopache area

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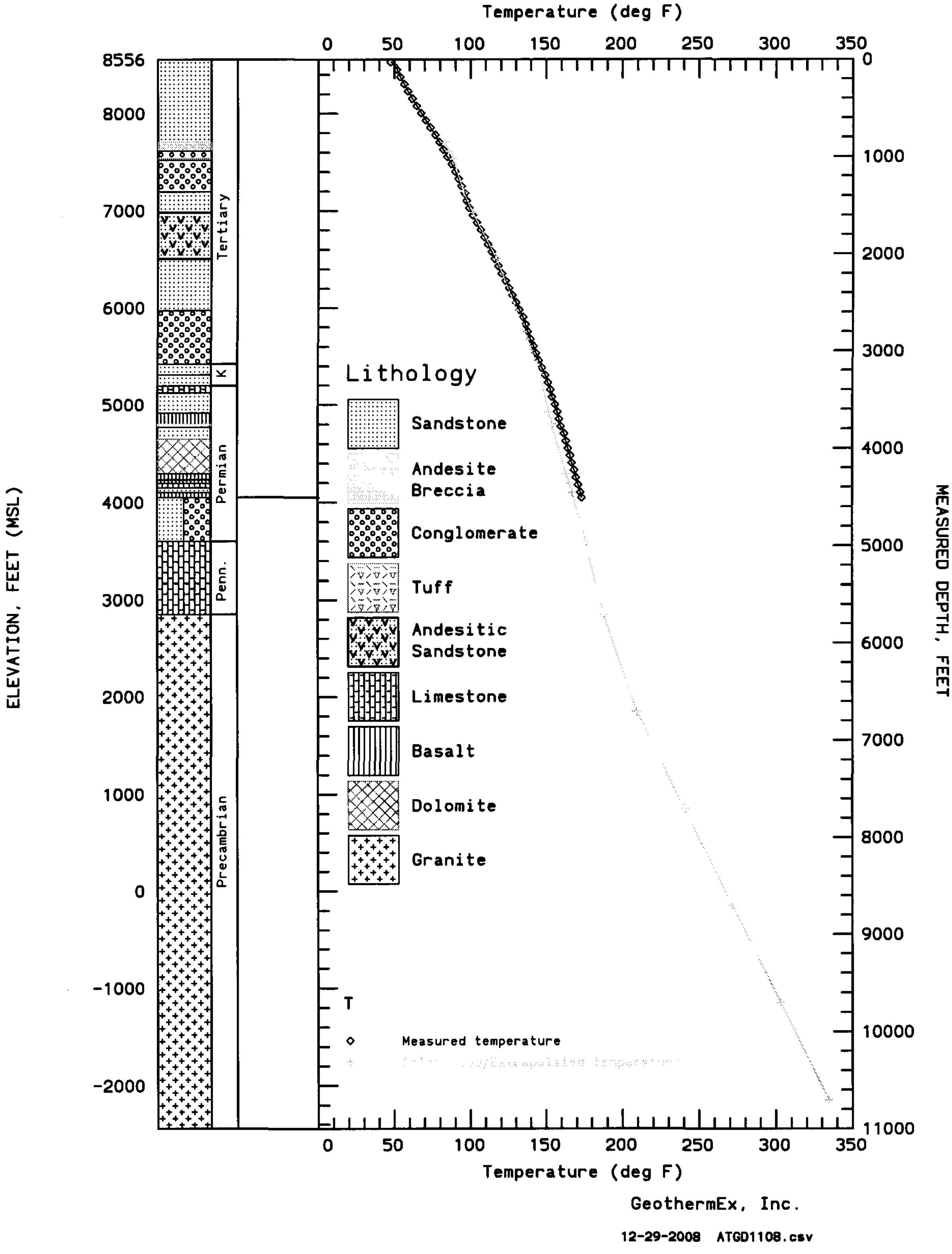
Figure 3.7: Measured and extrapolated temperature data
Alpine 1 core hole



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basement is generally encountered at shallower depths (higher elevations) in the Navopache area (Figure 3.8). EGS development is likely to be more favorable in areas where a thick section of insulating sediments cover the basement rock, trapping the heat below.

EGS development requires a significant amount of water for stimulation and operation (and for drilling, although this is a normal requirement for a geothermal well). Stimulation may require several million gallons of water, and some net water loss during operation can be expected. Therefore it is important to consider the groundwater resources available in the area. A regional aquifer is known to exist in the Coconino sandstone (equivalent to the Glorieta sandstone in New Mexico). The elevation of the top of this sandstone and its thickness are shown in Figures 3.9 and 3.10, respectively.

This aquifer is part of a composite aquifer in the Alpine-Nutrioso area and consists of the Cretaceous Dakota Sandstone, Permian San Andres (Kaibab), and Permian Glorieta (Coconino). This hydrogeologic unit is 393 feet thick in the Alpine 1 core hole. The aquifer is buried beneath a major aquitard consisting of mid-Tertiary volcaniclastic sediments and Laramide basin fill (Mogollon Rim Formation and Eagar Formations). This aquifer system probably has a shallow dip to the south with a hinge line or fault zone(s) between Nutrioso and current production from the Coconino north of Springerville. There is insufficient information available to determine is the aquifer beneath Nutrioso and Alpine 1 core hole is a recharge source for the current production from the Coconino north of Springerville. However, it is believed that most recharge and inflow to the current production areas is from the east and northeast out of the New Mexico subsurface north of the Salt Lake Fault Zone (Akers, 1964; Mann, 1976). If this is true, then a significant water resource is available in the Dakota-San Andres-Glorieta composite aquifer beneath Nutrioso and Alpine region that will not accrue significant impact to existing water rights in the Coconino aquifer north of Springerville. A detailed hydrogeologic study would be needed to confirm this hypothesis.

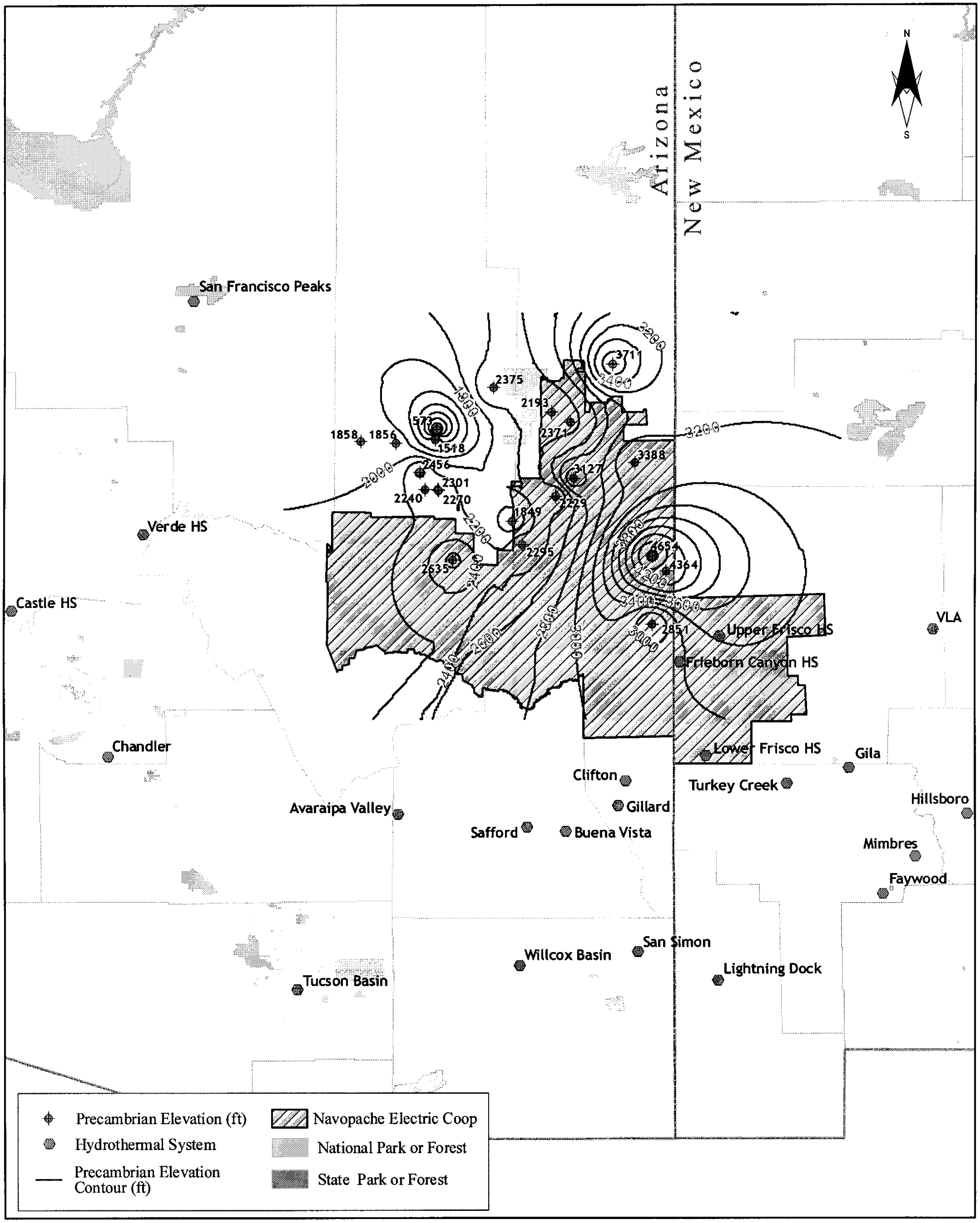

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Figure 3.8: Structural contour map on the top of Precambrian basement, Navopache Electric Coop area

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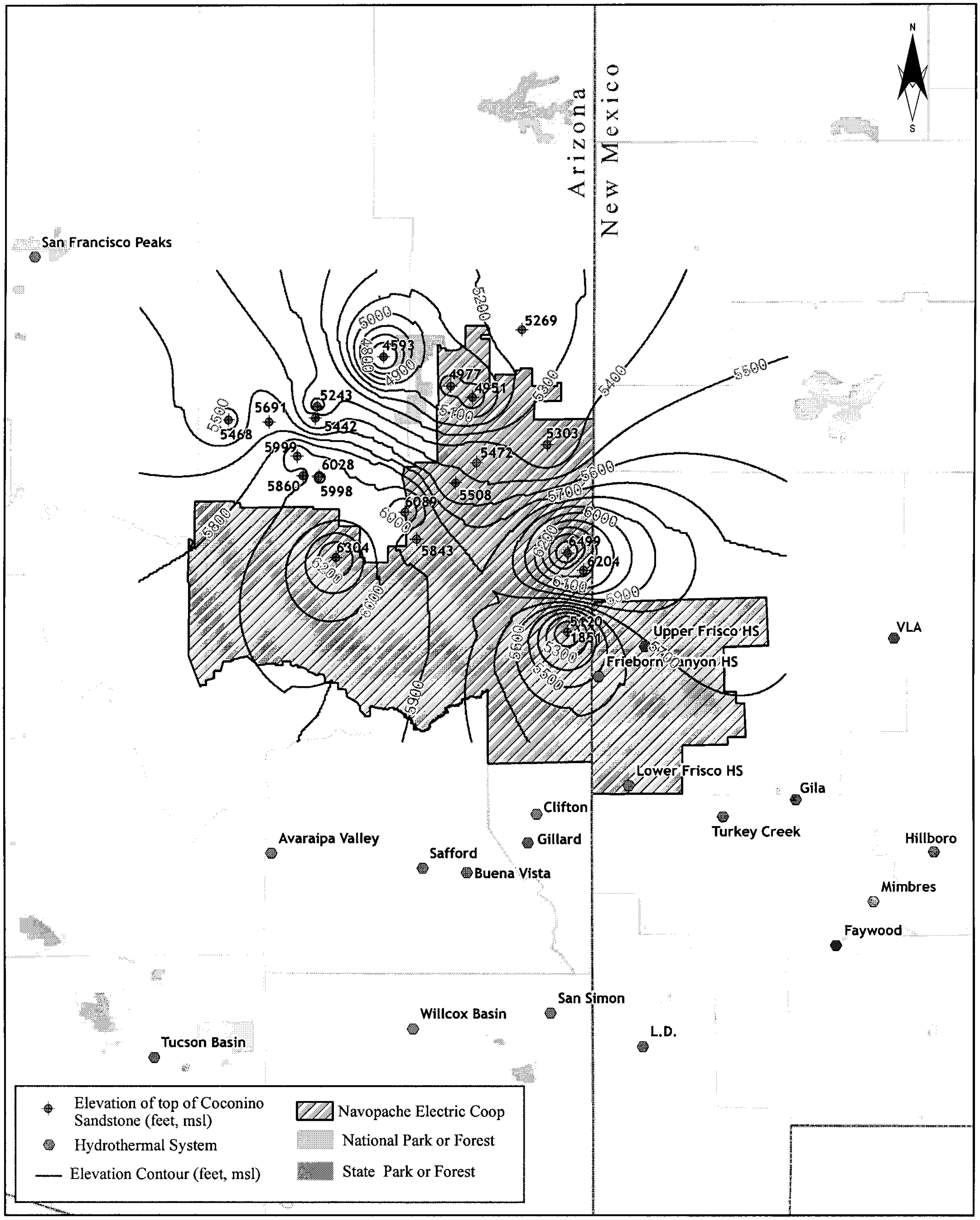

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Figure 3.9: Structural contour map on the top of the Coconino sandstone aquifer, Navopache Electric Coop area

GeothermEx, Inc.

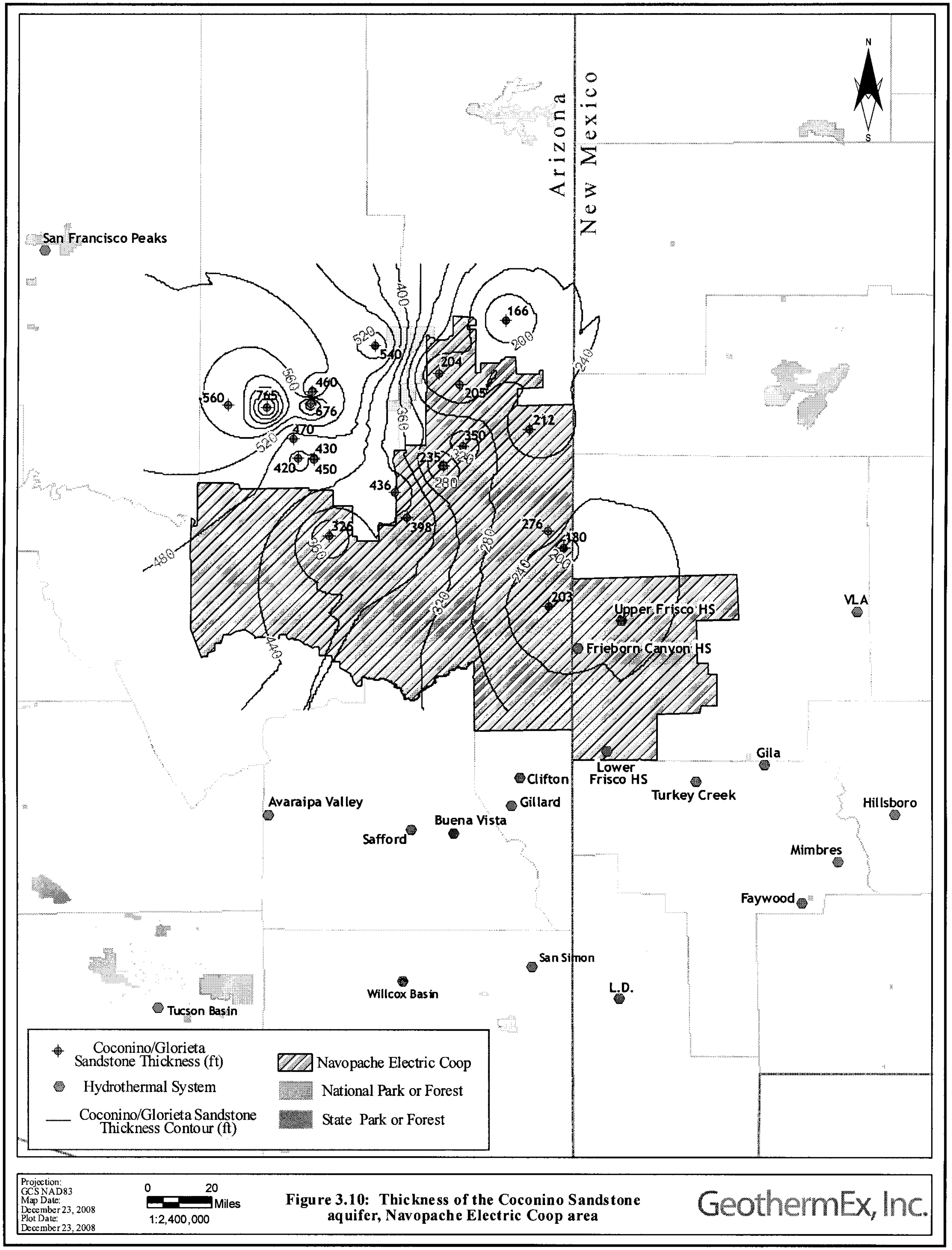

Figure 3.10: Thickness of the Coconino Sandstone aquifer, Navopache Electric Coop area

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A second groundwater resource in this region is contained in permeable zones between basalt flows on the eastern flanks of the White Mountain volcanic field (Figure 3.1). While significant ground water is no doubt present, a potential conflict exists between use of the water and Federal reserved rights for recreation and wildlife purposes. There are many lakes in the high country between Nutrioso and the White Mountains that are important for fishing and wildlife in the area. While recharge is no doubt very high due to winter and summer monsoon precipitation, this area is also the headwaters for the Little Colorado River, and production of ground water from the basalts may have an impact on downstream water use.

3.6 Geothermal Potential Outside the Navopache Service Territory

It is possible that Navopache could purchase electricity from conventional geothermal resources, all of which are located outside beyond the boundaries of the Navopache service territory. Figure 3.11 shows the locations of known hydrothermal resources, transmission lines and land status in vicinity of the Navopache area. Of these, the most promising in Arizona are likely to be the San Francisco Peaks area north of Flagstaff, Verde Hot Springs south of Flagstaff, and the Clifton and Gillard areas, south of the Navopache service area near the eastern border of Arizona. In New Mexico, there are two potentially interesting areas: the so-called "VLA" area in the Augustin Valley, and the Hillsboro Hot Spring area to the south. Little is known about the former. Lightning Dock is also prospective for power generation, but developers are already active there and probably have made at least preliminary arrangements with other power purchasers.

These opportunities are discussed briefly below.

3.6.1 San Francisco Peaks

The San Francisco Peaks area is one of the most attractive geothermal prospects Arizona. Because the volcanic field is very young and has erupted a large volume of silicic volcanic rocks (see Figure 3.1), it has long been postulated that a significant "blind" geothermal system (one

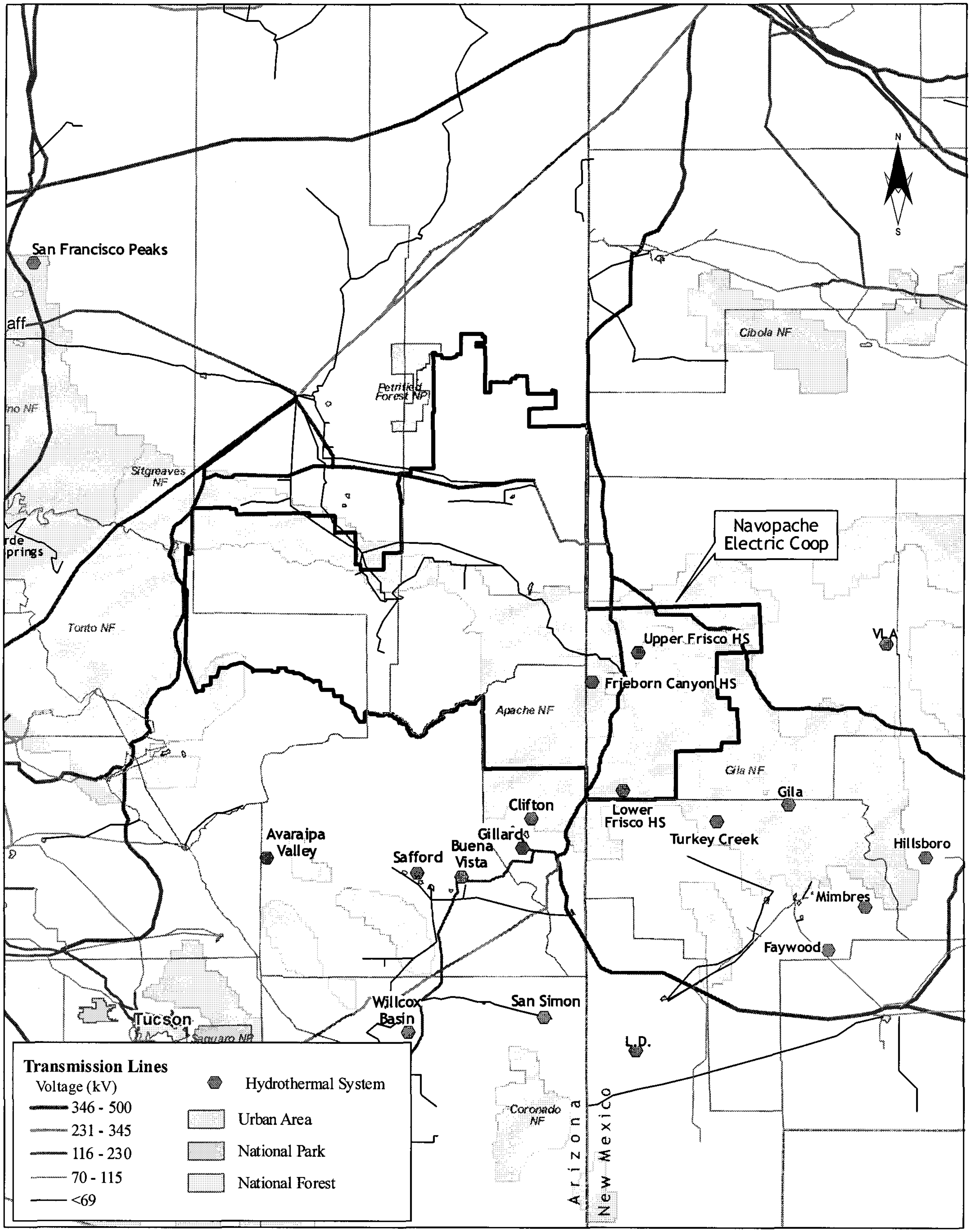

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Figure 3.11: Transmission lines, known geothermal resources & land status, Navopache Coop area

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with no surface manifestations such as hot springs) may exist, perhaps beneath the areas around the youngest volcanic vents. The volume of young silicic volcanic rocks compares favorably with other volcanic areas in the western US that host high-temperature geothermal systems and are currently producing commercial geothermal power.

The presence of young silicic volcanism is very attractive for the formation of geothermal systems. The apparent volume (100 km^3) and youth (0.05 to 0.21 Ma) of the erupted silicic volcanic rocks in parts of the area provide the motivation to explore this area because of the likelihood of finding significant, useable geothermal heat. On the other hand, other than the age and erupted volume, issues relating to magmatic evolution remain poorly resolved, and are important vis-à-vis the magnitude and longevity of heat production in the subsurface.

The San Francisco Peaks area could host geothermal resources with a power potential of at least several tens of MW and perhaps significantly more. It could be the most significant geothermal resource in Arizona. While the potential appears to be great, only minimal geothermal exploration has been undertaken in this area; much work remains to be done to accurately assess the geothermal potential. The area is not yet close to demonstration of the feasibility of geothermal power generation.

The presence of major 345 kV and 500 kV transmission lines (running from Page to Phoenix and Las Vegas) in the area is favorable for geothermal development in the area. However, justification for large expenditures (*e.g.*, for drilling a deep exploratory well) would logically be undertaken only after evaluating certain other logistical issues. The most important of these is land status and how it would affect the ability to explore for and develop a geothermal resource. Most of the prospective area is located on US Forest Service land, which would need to be leased from the Federal government.

The recently approved Programmatic EIS (PEIS) has eased the geothermal leasing situation for Federal lands. Per the Record of Decision (ROD) for the PEIS (signed on 17 December 2008),

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the PEIS will facilitate geothermal leasing of Federal mineral rights in 12 western states (Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming). The PEIS identifies BLM and Forest Service lands that are now open or closed for geothermal leasing and provides certain stipulations, practices, and procedures for geothermal leasing and development. These actions will be implemented as BLM resource management plan amendments for 114 land use plans (no such amendments are specified for any US Forest Service land use plans). This ROD does not authorize any ground-disturbing activities or waive the environmental review and NEPA compliance requirements for subsequent geothermal exploration, drilling, utilization, and reclamation permits, but it does enable a long-standing backlog of leases to be issued, and clears the way for additional geothermal leasing of Federal lands.

The back-logged leases were applied for under now-defunct rules for Federal geothermal leasing, which allowed leases to be issued on a non-competitive basis unless they were within a delineated Known Geothermal Resource Area (KGRA). Recent geothermal leasing rules enacted in 2006 make all geothermal lease sales competitive, essentially abolishing the KGRA designation. The current process requires potential developers to nominate lands for leasing. The nominations are submitted to the appropriate agency that manages the surface (typically BLM or the US Forest Service), which then undertakes a preliminary environmental review of the nominated lands to determine if they should be offered for lease or not, based on environmental considerations. Nominated land parcels that pass this environmental review may be subject to stipulations about the types of activities that are allowed or disallowed. The land parcels approved for leasing are then offered in competitive lease sales wherein the parcels are leased to the highest bidder. This means that although one party may nominate lands, any party may win the geothermal rights to those lands.

The area of youngest volcanism lies within the Sunset Crater National Monument, which is adjacent to the area that looks most prospective for development, may hinder development because of perceptions that the Monument would somehow be affected. Because Native

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Americans in the area view the nearby San Francisco Mountain as sacred, consultation and education of Native Americans in the area will be crucial for a successful development. The availability of water and the costs and impacts associated with obtaining water for drilling and other activities will require study.

3.6.2 Clifton

Arizona's highest-temperature spring systems are located in the Clifton-Gillard-Morenci region of southeastern Arizona (Figure 2.1). One of these spring systems, Clifton Hot Springs, represents an amalgamation of many spring discharges along a 3 to 4-mile stretch beneath and along the banks of the San Francisco River. The geothermal system at Clifton Hot Springs is located adjacent one of the largest copper mining operations in the world, at Morenci, and it is likely that any development would require the cooperation of Freeport McMoRan Copper and Gold, Inc. (the owner/operator of the Morenci mine).

The Clifton geothermal system represents a "thermal sweep" system in fractured Precambrian granite. Recharge may encompass a large portion of the San Francisco River basin, where higher elevations provide significant precipitation, especially in the winter. In a "thermal sweep" system, water level differences between high elevation recharge areas and lower elevation discharge areas (*i.e.*, hot springs area) provide the potential drive to force water to flow to great depth where it is heated by the background temperature gradient. Structurally high and fractured rocks in the discharge area provide vertical discharge window(s) for deep regional lateral seepage to flow rapidly upward. The discharge or hydrogeologic window is contained in fractured Precambrian rock on and adjacent to fault zones of the San Francisco half graben. Certainly, the shallow part of the upflow reservoir is mixing with non-thermal water. Geothermometers indicate potential of a 150°C temperature reservoir. Depth to the 150°C isotherm in the reservoir may depend upon the vertical flow velocity (or permeability).

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The canyon topography of the Clifton geothermal system environment makes exploration difficult. In addition, the areas that appear most favorable to drilling are located on lands that are either privately owned or on land controlled by Freeport McMoRan as a part of its mining operation at nearby Morenci. Because Freeport McMoRan is a significant power user, geothermal exploration and development at Clifton would be well-suited to a partnership with Freeport McMoRan. In addition to the Freeport McMoRan lands, there are both Federal land and other private lands within the zone of geothermal interest.

Because geothermal development could decrease the natural flow of saline waters from hot springs and seeps into the San Francisco River, geothermal development could have a positive impact on downstream water quality. Consultation with Freeport McMoRan, ADWR, and a study of potential shallow, volcanic-hosted aquifers north of Clifton will be required to understand water availability for geothermal power generation.

3.6.3 Gillard Hot Springs

Arizona's highest-temperature spring (82 to 84°C) is located along the north bank of the Gila River south of Morenci in southeastern Arizona. Small tracts of Federal land adjacent to the hot spring encompass one of the two areas formerly designated as KGRAs in Arizona (the Gillard KGRA). Like Clifton Hot Springs, the geothermal system at Gillard Hot Springs is located near the Morenci mine.

Individual spring discharges along the banks of the Gila River include seeps with flows of up to a few gpm (Witcher, 1981). Larger discharges are likely to occur in the bottom of the river. Measured temperatures range from 80 to 84°C and have sodium chloride chemistry and total dissolved solids that range up to 1,500 mg/l (Witcher, 1981). Significant mixing with shallow near surface ground water is not observed. The quartz and Na-K-Ca geothemometers are 130°C and 139°C, respectively (Witcher, 1981). A stream flow and chloride balance for the Gila River

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above and below the hot springs indicate a natural composite geothermal flow rate of about 400 gpm (Witcher, 1981).

The canyon topography of the Gillard geothermal system environment makes exploration difficult with most geophysical methods. Gillard Hot Springs proper lies within the Gila Box Riparian National Conservation Area, which is off-limits for development. Therefore, exploration for a geothermal reservoir would need to be undertaken beyond the Gila Box boundaries, *i.e.*, further north in the Duncan Basin or in bedrock in the Peloncillo Mountains to the south.

Production of geothermal fluids could affect the flow of Gillard Hot Springs and might be perceived as an ecological problem by environmental groups or Federal regulating agencies. Phelps Dodge could view geothermal development at Gillard as a potential impact on its operations as well. Large leachate tailings are located to the north of the hot springs, and a large cone of depression from geothermal production could detrimentally affect monitoring of tailings leaks and any required mitigation. On the other hand, reducing the flow Gillard Hot Springs would increase the water quality in the Gila River.

Although road access in and around the Gillard area is somewhat limited at present, the topography does not present any formidable obstacles to exploration and development. Aside from the presence of the Riparian Conservation Area and the operations of Phelps Dodge, logistical conditions are relatively favorable. Transmission lines from the Safford area to the mining operations at Morenci are located nearby the Gillard area.

3.6.4 Verde Hot Springs

Verde Hot Spring is well known, and has one of the higher surface discharge temperatures of springs in Arizona. While Verde Hot Spring is in a somewhat remote location, high-capacity transmission lines traverse the area within a mile or two of the hot springs. No exploration for geothermal resources has been done in the area, other than the collection of water samples for

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geochemical evaluation. Neogene volcanism in the region attests to enhanced thermal conditions in the upper mantle. Very few heat flow measurements are available in the region, and none are very close Verde Hot Springs. Sass *et al.* (1994) infer a regional heat flow in the Verde Hot Springs area between 60 to 80 mW/m^2.

The Mogollon Rim (the uplifted margin or escarpment of the Colorado Plateau) receives significant winter snow and summer monsoon precipitation. Because much of the precipitation recharges regional Paleozoic aquifers, large springs discharge south of the Mogollon Rim in many canyons within the Transition Zone (see Figure 2.1). Some the largest springs in Arizona are observed in Fossil Creek about 10 mi (16 km) east of Verde Hot Springs (Feth and Hem, 1963). The travertine-depositing springs in Fossil Creek release over 21,000 gpm. Verde Hot Spring is found at the south end of Verde Basin along the west bank of the south flowing Verde River.

Verde Hot Spring discharges between 10 and 50 gpm of sodium bicarbonate sulfate water at temperatures between 36 and 40°C (Mariner *et al.*, 1977). Total dissolved solids range between 3,667 and 3,931 mg/l. The silica (quartz) geothermometer is 122°C and the Na-K-Ca cation geothermometer is 153°C. Paleo travertine deposits are associated with Verde Hot Spring. About 6 mi (9.6 km) north of Verde Hot Spring, Brown Spring discharges from a large travertine mound complex (Nations *et al.*, 1981). Brown Spring temperature (22°C) is slightly higher than most springs in the Verde Valley, but is not statistically anomalous when surface mean annual temperature variations are accounted. However, the silica content is high at 54 mg/l (Twenter and Metzger, 1963). Brown Spring may have a geothermal component and indicate more extensive activity than observed at Verde Hot Spring. On the other hand, the measured pH is high at 8.0 and the water may be buffered by soluble glassy silica from tuffaceous rocks.

Access to the area is limited to an unpaved county road from Camp Verde in the Verde Valley. The road from Strawberry down Fossil Creek is unsuitable due to switchbacks and narrow one-lane sections. The bulk of the land around Verde Hot Spring lies within the Prescott National

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Forest (US Forest Service). Two 345 kV high capacity transmission lines traverse the area within a mile or two of the hot springs. Assessment of the availability of water for power requirements will require a study or consultation with Arizona Public Service (APS) as APS likely has the surface water rights on nearby Fossil Creek.

3.6.5 Other New Mexico Resources

The Hillsboro Warm Springs is an additional potential geothermal produced for Navopache. While the site is well beyond the service area, it has several attributes worth discussion. First is the fact that the site is located adjacent to an important transmission line that was built to supply power to an open pit copper mine operation. Second, the site has received some exploration activity by way of temperature gradient and heat flow drilling, SP surface electrical geophysics, and 1:24,000 scale geologic mapping. The Hillsboro Warm Springs are associated with siliceous sinter and discharge at a low flow rate in the western bounding fault zone of the Animas Mountains. The fault zone may also demarcate an outer ring fracture zone of the Emory cauldron, one of the largest mid-Tertiary resurgent cauldrons identified in the western Cordillera. Ring fracture zones of old long since cooled ignimbrite calderas frequently provide favorable plumbing for geothermal reservoirs and upflow zones. The Lightning Dock geothermal system in southwest New Mexico is an example (Elston *et al.*, 1976 and Witcher, 2008).

Temperature gradient drilling at Hillsboro has encountered 80°C fluids at less than 250 feet depth. The sodium bicarbonate-sulfate waters have low TDS, less than 600 mg/L and discharge at a temperature of 34°C. Silica concentration is 151 mg/L and appears to indicate potential for a geothermal reservoir over 120°C. The system appears to be small, but is an attractive geothermal prospect considering that power transmission is available and the favorable conditions indicated by the limited geothermal studies undertaken to date.

North of the Hillsboro area is a region where geothermometry from spring waters suggest the presence of another geothermal system. This is in the Augustin Valley, where the Very Large

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Array (VLA) radio telescope is located. Little is known about this area, and its geothermometry may be affected by the playa geology. Although not as favorably located relative to transmission as the Hillsboro area, it may have some geothermal potential.

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4. RESOURCE POTENTIAL IN THE MOJAVE COOP AREA

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5. EXPLORATION AND DEVELOPMENT PLANNING AND COSTS

5.1 Arizona Permitting Overview

The laws relating to geothermal resources in the State of Arizona are contained in Arizona Revised Statutes, Title 27 Minerals, Gas and Oil, Chapter 4, Article 4 - Geothermal Resources (ARS 27.651-677). Administrative rules and regulations supporting ARS 27.651-677 can be found in Arizona Administrative Code R12.7.101-199.

In the State of Arizona "geothermal resources" are defined as:

- All products of geothermal processes embracing indigenous steam, hot water and hot brines.
- Steam and other gases, hot water and hot brines resulting from water, other fluids or gas artificially introduced into geothermal formations.
- Heat or other associated energy found in geothermal formations, including any artificial stimulation or introduction thereof.
- Any mineral or minerals, exclusive of fossil fuels and helium gas, which may be present in solution or in association with geothermal steam, hot water or brines.

The drilling of all geothermal wells, whether for temperature gradient measurements, power generation (production and injection wells) or direct use (production and injection wells) on all land (including tribal lands) in Arizona is overseen by the Oil and Gas Conservation Commission (OGCC). The Bureau of Land Management (BLM) will also be involved if the well is located on non-tribal Federal land. A production well would also require a production permit (or water right) and filing of a notice of intent to drill with ADWR or at the minimum consultation and production reporting (metering). The Arizona State Land Department is a regulator on State Trust lands for production reporting and royalty assessment.

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The Arizona Department of Water Resources (ADWR) is the lead agency responsible for regulating all water wells, monitoring wells, geothermal wells, and injection wells. Once a developer acquires the rights to a land block that is zoned to allow geothermal development, they must secure the drilling permits from OGCC and the water rights from ADWR. Obtaining the water rights will depend strongly on both the location of the well and the amount of water pumped. The primary determinant in how the well is regulated is its location relative to the Active Management Areas (AMAs). As shown in Figure 5.1, there are five AMAs in the state: Phoenix, Tucson, Pinal, Prescott and Santa Cruz. In the AMAs, the role of ADWR is primary because of the extreme importance of water rights issues in these areas. There are no AMAs coincident with the Navopache or Mojave Coop areas.

The disposal options available include underground injection; disposal to surface waters; and/or, disposal to the ground or land application. Regulators may specify the preferred option, particularly in critical groundwater areas, where injection is likely to be required. Injection wells permits are obtained from the Arizona Department of Environmental Quality (ADEQ) and/or the Environmental Protection Agency (EPA). The ADEQ's Water Quality Division is responsible for administering surface disposal of wastewater, including geothermal fluids, while EPA Region 9 has regulatory authority over injection wells (in cooperation with the OGCC and ADEQ). Injection wells will need to be permitted with consultation and sign-off approval by AZGS, OGCC, ADEQ and ADWR. ADEQ would be the lead agency for injection wells, since it oversees the quality of groundwater resources in the state and administers an Aquifer Protection Permit (APP) program. An APP is required if fluid will be discharged to an aquifer, land surface or underground in such a manner that there is a reasonable probability that any pollutants will reach an aquifer. ADEQ determines if an APP is required or if the project is exempt from such requirements.

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5.2 Exploration and Development of Conventional Hydrothermal Resources

Although each geothermal system (along with the environment in which it occurs) is unique to some degree, there are a number of elements that are common to successful exploration and development programs in most, if not all, geothermal fields. The common elements include planning/strategic aspects of the programs as well as many of the activities that are components of the programs.

5.2.1 Activities

Exploration-stage activities are generally designed to identify and delineate the zone in which the geothermal reservoir occurs, and have the ultimate objective of a commercial resource discovery in the form of one or more productive wells. Development-stage activities are aimed at demonstrating the feasibility of commercial development of a project of given size, and, ultimately, at completing the production and injection wells needed to support the project initially. Each step in both the exploration and development stages is designed to provide more information and a greater understanding of subsurface conditions, including such parameters as the extent, temperature and patterns of fluid movement within the geothermal system, as well as the geologic setting and structure of the system. This information is accumulated and used to update a conceptual model of the geothermal resource, which evolves to form the basis for the continued planning of the exploration and development process. By the end of the development stage, a numerical model of the geothermal reservoir is often developed, to serve as a quantitative tool for operating and managing the field.

The exploration and development process also tends to proceed from less-expensive activities to more-expensive activities. With each successive step, the increased understanding of the resource should lead to a reduction of resource risk (that is, the risk of failure in the exploration or development process), so that the greater investment required for the next step is justified on a risk/reward basis. In practice, the least expensive activities are generally those that can be

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performed on the ground surface (without the need for drilling). Costs increase for activities that require shallow drilling, and increase further as deep drilling as needed. Thus, the exploration and development process tends to proceed from surface or shallow investigations over a broad area toward deep drilling within a more reduced zone where the geothermal reservoir has been found or inferred to occur.

Activities that take place in most geothermal projects at the exploration stage include:

- Verification that surface mapping of the local and regional geology is adequate, with additional mapping being performed as needed.
- Identification of all thermal manifestations in the area (including, particularly, warm and hot springs and fumaroles). Samples are collected and analyzed from all available surface discharges of thermal fluids, if this has not been done previously, and a geochemical interpretation of the results is made to assess possible subsurface temperatures (through chemical geothermometry) and other aspects of fluid chemistry.
- Selected geophysical surveys. The geophysical methods that may be effective in interpreting subsurface geologic and/or hydrothermal conditions vary significantly with differences in geologic setting. Some combination of electrical resistivity methods, magnetometry, seismic methods and gravimetry is often applied.
- Shallow drilling to measure temperature gradients (and in many cases to estimate heat flows) in the area of interest.
- Drilling of one or more deep exploratory wells, which in some cases may be of smaller diameter than typical production wells (in order to reduce cost at this more risky stage).

Activities common to most development programs include:

- Further deep drilling to confirm the extent, production capacity and other characteristics of the resource, and to develop the initial production capacity needed for the project.

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- Testing of wells, including short to long-terms tests that may include monitoring of pressure interference between wells.
- Interpretation of the chemistry of the geothermal reservoir through sampling and analysis of fluids produced during well testing.
- Definition of appropriate zones for injection, and the drilling of the wells to supply the initial injection capacity for the project.
- Estimation of the recoverable energy reserves of the geothermal system (from deep drilling results), to ensure that the reservoir will support the project over its intended lifetime.
- Numerical modeling, to develop a quantitative model for predicting the behavior of the reservoir under exploitation.

It is likely that the exploration and development program would include these basic activities for most or all prospective areas with conventional hydrothermal resources, provided that the results at each step are encouraging enough to proceed.

5.2.2 Cost and Time Requirements

The costs and time required for exploration and development programs can vary considerably, and depend on various factors such as the size of the project being considered, the geologic conditions of the resource area, regulatory constraints, and the availability and cost of services and materials at the time the work is undertaken. In addition, the nature of the exploration process means that the course of an exploration program, and even a development program, can change as the work proceeds. As a result, it can be difficult to accurately estimate exploration and development times and costs, even when many specific characteristics of the project are known.

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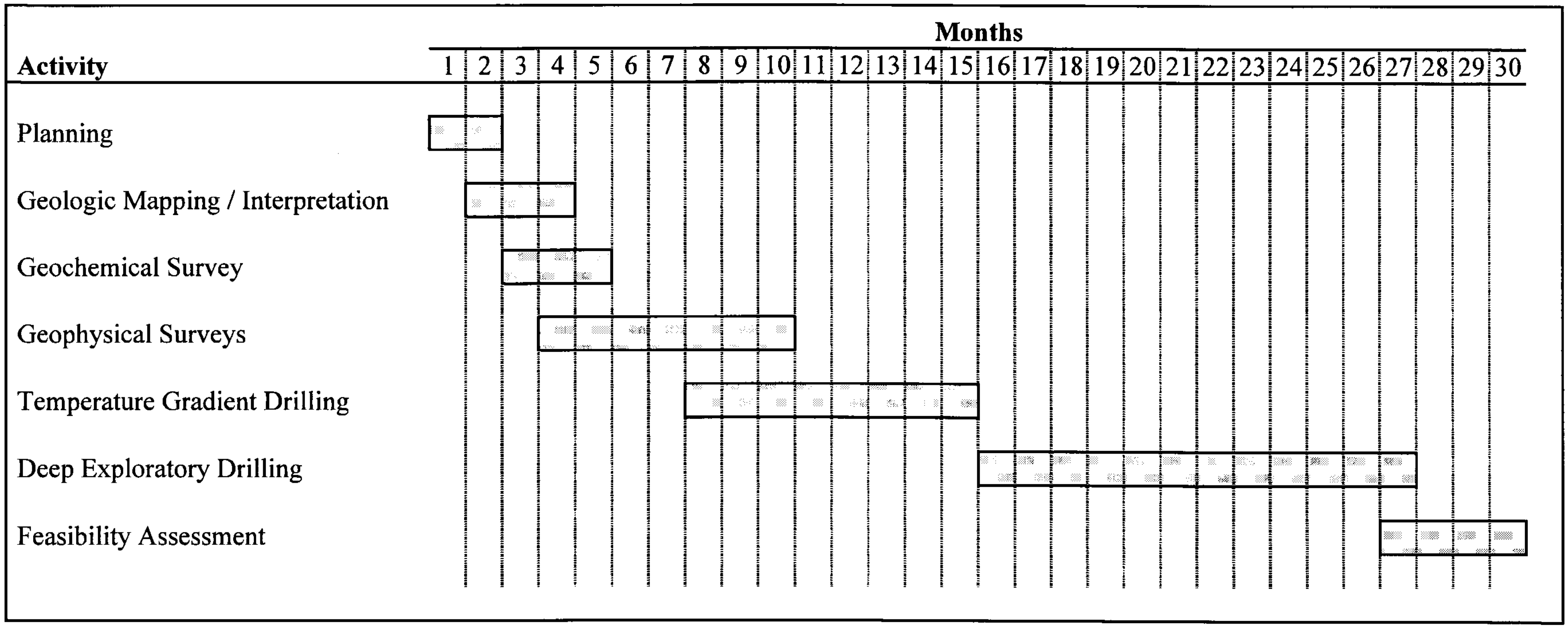
Some generalizations can nevertheless be made about the cost and schedule for typical exploration and development efforts, under conditions that frequently (but not always) prevail. Table 5.1 presents typical ranges of cost and time requirements for the various activities that need to be carried out in the course of exploration and development, as described above. Figure 5.1 shows a timeline for a hypothetical exploration program, in which the times for the different activities are close to the median values that might occur within the "typical" ranges. The total time required for development (once the exploration stage has been completed) is strongly dependent on project size, and therefore it is impractical to present a representative timeline for development.

As Table 5.1 indicates, drilling accounts for the majority of costs in both the exploration and development phases of work. In the exploration phase, the costs of geologic mapping and other geologic analysis, and of geochemical studies, tend to be modest compared with drilling costs, whereas geophysical surveys can, in some projects, represent a significant expense (up to several hundred thousand dollars). Assessment of project feasibility (based on exploration results) can also be a significant expense, depending on project size (among other factors). As the figures presented in Table 5.1 indicate, the total cost of an exploration program may typically vary between about $1.5 million and $6 million (with variations in drilling cost accounting for most of this range). The time required to complete an exploration program is typically in the range of 2 to 3 years, though, for some smaller projects, it might be possible to complete the program in a slightly shorter time.

As noted, the time and cost of a development program is heavily dependent on project size. For a very small project (based, for example, on a single production well and single injection well), development (including power plant construction) might be completed in as little as about two years, whereas the time required for a large project is likely to be considerably longer. The cost of wellfield development will be largely a function of the project size and the cost, productivity and success rate for typical wells.

Figure 5.1: Median timeline for a conventional hydrothermal exploration program



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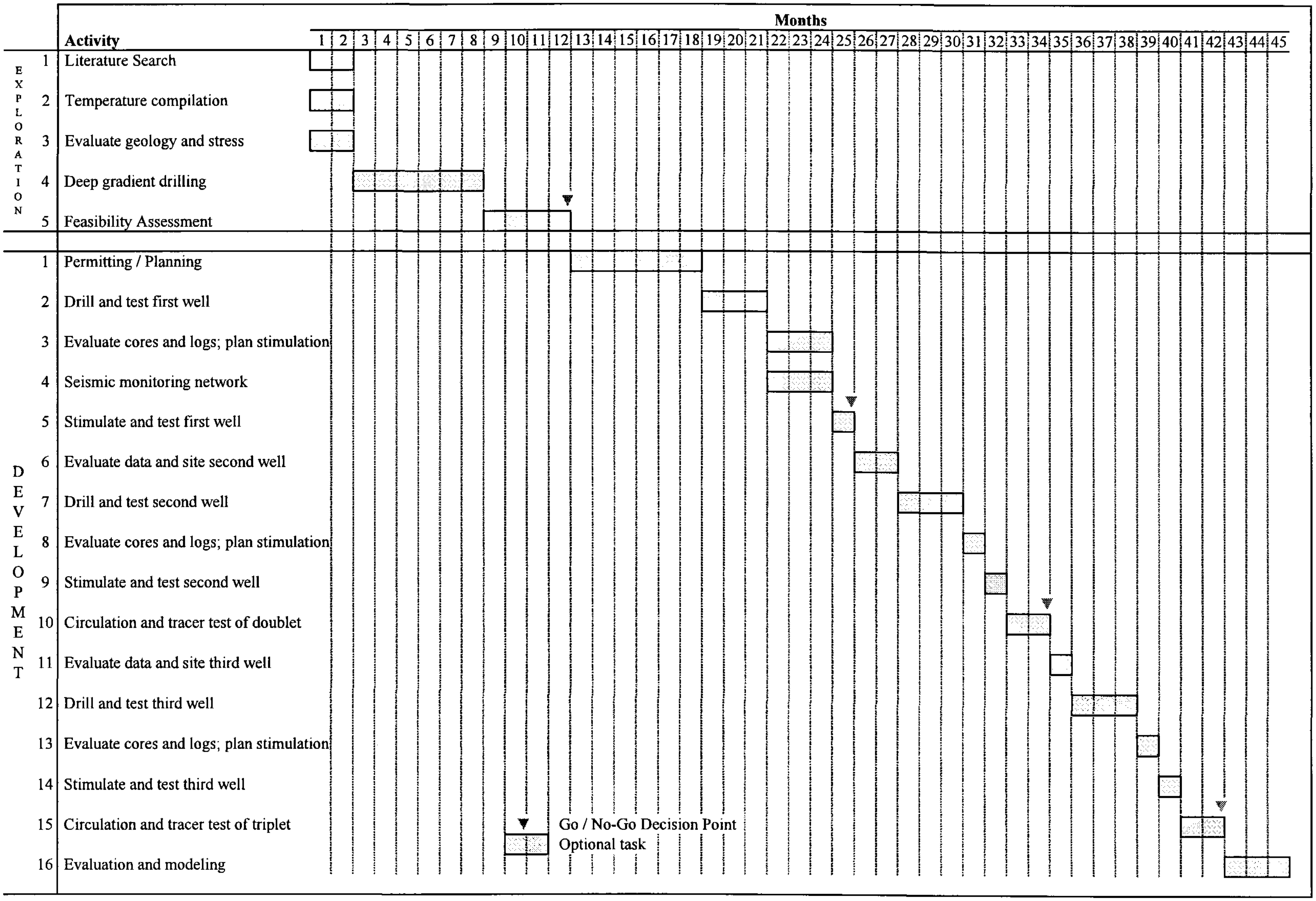
5.3 EGS Development Steps and Costs

The process of EGS development is quite different, as described below (and as indicated in Table 5.2 and Figure 5.2):

- Find and evaluate data to determine subsurface temperatures.
- Identify rock formations suitable for hydraulic stimulation.
- Find and evaluate data to confirm the stress field orientation, These would ideally be in the form of wellbore image logs from oil & gas test wells; however, if such information is not available, then one must rely on the predominant direction and mode of slip on young faults, and other indicators of stress orientation, as discussed in Chapter 3 of this report.
- Site the first well in a location that would enable perhaps 1,500-2,000 feet of separation between it and the second well, considering the stress orientation. For example, if the direction is confirmed to be WNW, then the wells need to be separated by ~1,500 feet in the WNW direction (and ideally there would be room for a third well too).
- Drill, core, "mini-frac," log and injection test the first hole, which would be drilled into the Precambrian basement to perhaps 11,500 feet and cased at about 10,000 feet.
  - The mini-frac would be conducted after setting the production casing shoe and drilling a very short section of hole below the shoe. The mini-frac is a way to determine the magnitude of the minimum horizontal stress, and is essentially a frac job on a short section of hole in the intended reservoir formation. Water is pumped in at high pressures and the pressure at which the rock breaks down (*i.e.*, the pressure at which tensile failure occurs) is determined.
  - Core would be collected from the intended EGS reservoir interval to determine rock strength and other properties.

Figure 5.2: Estimated timeline for a small EGS development program



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  - Geophysical logs would be run, including sonic-density-porosity (with gamma), a wellbore image log (with gamma) and of course temperature-pressure logs. Logs would be run to the casing point (before casing) and below in the open hole section.
  - An injection test would be run with the rig on site (using the rig pumps) to characterize pre-stimulation hydraulic characteristics of the potential reservoir.

- Evaluate the wellbore image logs for stress direction and characterization of natural fracture population.
- Determine the mechanical properties of core samples.
- Plan the stimulation.
- Set up a seismic monitoring network.
- Stimulate the well by injecting water over a period of several days, with downhole pressure monitoring and periodic pressure-temperature-spinner logging. Monitor seismicity, hopefully with real-time event location to see how the stimulation is going.
- Conduct and evaluate post-stimulation injection test (using pump trucks that were brought for stimulation job).
- Evaluate seismic and injection test data to site the second well of the doublet.
- Drill, core, mini-frac, log and test second hole (with pressure monitoring in first hole). Stimulate if needed to improve connection between the two wells. Continue seismic monitoring.
- Perform a circulation and tracer test between the two wells (while continuing to monitor seismicity) and determine if a third well is needed to achieve the desired output. If so, follow a similar program for the third well.

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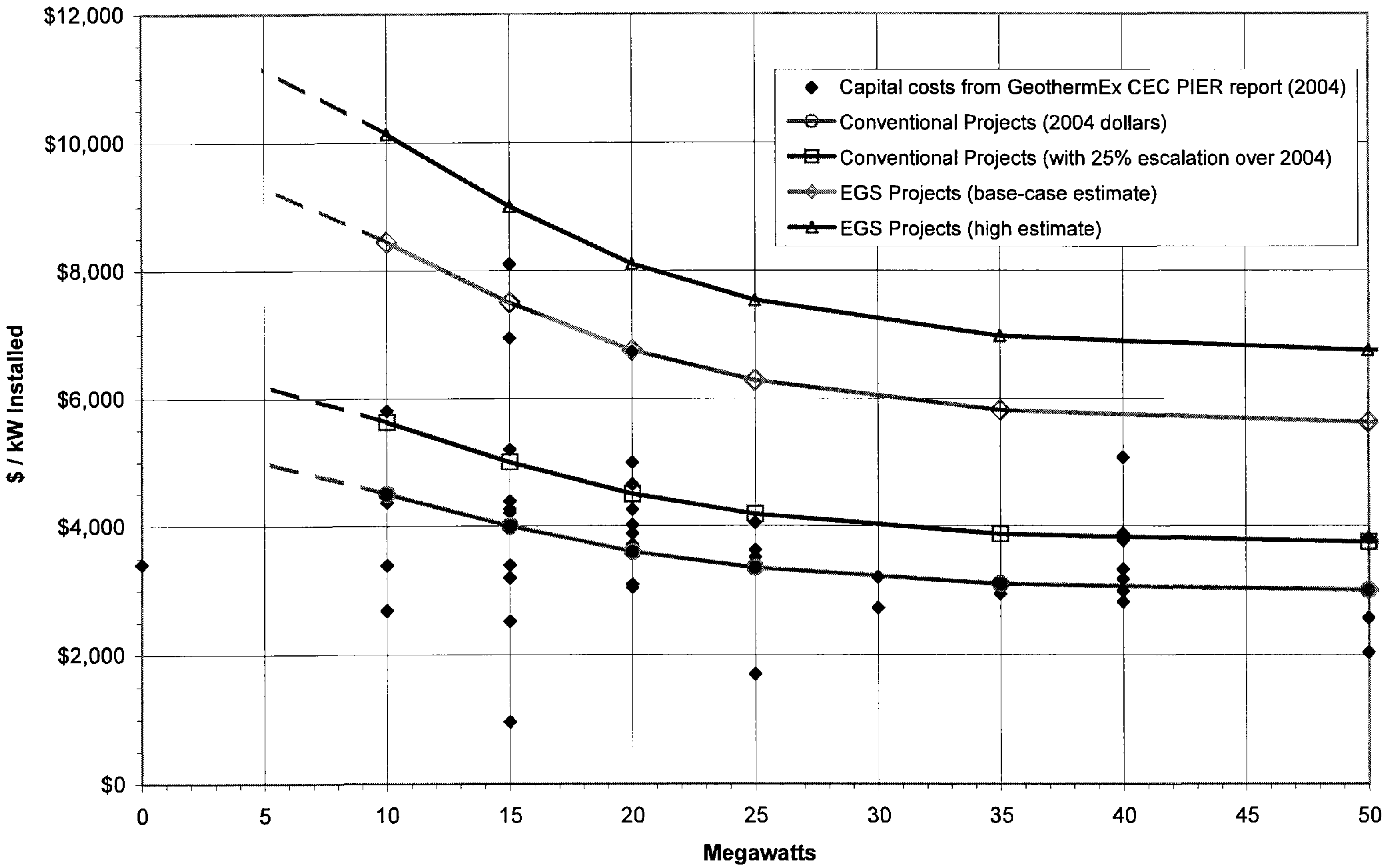
The overall costs of geothermal development, including both the wellfield and power plant, are presented in Figure 5.3. These data, based on actual costs for conventional hydrothermal developments of 10 MW or more in the United States, were originally developed in 2004 for a report prepared by GeothermEx for the California Energy Commission (CEC), as part of their Public Interest Energy Research (PIER) program (GeothermEx, 2004). A visual best-fit curve through these data was made (the red line on Figure 5.3), then increased by 25% to account for the increases in drilling and power plant construction since the 2004 report was written (the blue line on Figure 5.3). Operations and maintenance costs are likely to be on the order of $0.025 to $0.030 per kW-hour.

Based on a large body of empirical data, the total costs of conventional geothermal power are approximately 60% power plant costs, and 40% wellfield costs. A small body of empirical data suggests that these ratios are reversed in EGS development, with the wellfield costing more than the power plant. These EGS ratios have been used to estimate a "base case" EGS cost line (the green line in Figure 5.3) using the escalated conventional hydrothermal costs. A high-case estimate is also made for EGS (the purple line in Figure 5.3), assuming a 20% increase on the EGS base-case costs.

For the potential EGS site in the Navopache area, an estimate of EGS development costs have been made. We assume that drilling costs for wells to 11,500 feet are likely to be on the order of $7 million per well, including stimulation. Power plant costs are likely to be on the order of $3500-$4000/kW. Assuming three wells are needed for a 5 MW project, the total costs would be on the order of $9,000/kW. This estimate would be reasonable for EGS developments of similar size and anticipated resource depth in either the Navopache or Mojave areas. Operations and maintenance costs are likely to be on the order of $0.025 per kW-hour.

Figure 5.3: Geothermal capital costs vs. capacity for small (<50 MW) conventional hydrothermal and EGS projects



RETI 1b costs + EGS cost for B&V 081211.xls

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TABLES

Table 3.1: Measured and Extrapolated Temperature Data, Alpine 1 Core Hole

Formation	Thickness ft	Depth ft	est Tcond W/m°K	Tgrad °C/km	Tgrad °F/100 ft	δT + MAT °F
Upper Spears	854	854	1.20	75	4.1	83
Andesite breccia (Dry Leggat Canyon)	88	942	2.10	43	2.4	70
Middle Spears	76	1,018	1.20	75	4.1	90
Tuff of Bishop Peak	20	1,038	2.20	41	2.2	71
Middle Spears (transition)	320	1,358	2.50	36	2.0	75
Middle Spears (pumaceous ss)	216	1,574	1.80	50	2.7	91
Lower Spears (andesite)	478	2,052	1.50	60	3.3	116
Eager Fm	1,087	3,139	2.00	45	2.5	125
Unnamed red beds	107	3,246	2.30	39	2.1	118
Dakota Sandstone	116	3,362	3.20	28	1.5	100
San Andres	74	3,436	3.10	29	1.6	103
Glorieta	203	3,639	4.00	23	1.2	93
Basalt	112	3,751	2.30	39	2.1	129
Corduroy member	515	4,266	2.80	32	1.8	123
Basalt	56	4,322	2.00	45	2.5	155
Fort Apache member	5	4,327	2.60	35	1.9	130
Basalt	35	4,362	2.30	39	2.1	142
Fort Apache member	43	4,405	2.60	35	1.9	132
Big A Butte member	49	4,454	2.60	35	1.9	133
Basalt	51	4,505	2.30	39	2.1	145
Amos Wash/Oak Creek member	450	4,955	2.80	32	1.8	135
Horquilla	750	5,705	3.10	29	1.6	139
Precambrian granite	1,000	6,705	2.30	39	2.1	192

Mean Annual Temperature (MAT)	9°C	48°F
Background Heat Flow	90	mW/m^2

Extrapolated data

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Table 5.1: Typical Budget and Time Requirements for Conventional Hydrothermal Exploration and Development

Exploration

Activity	Cost Range	Time Required	Comments
Geologic Mapping / Interpretation	$20K - $50K	3 - 6 months	May be concurrent with other activities
Geochemical Survey	$25K - $50K	3 - 6 months	May be concurrent with other activities
Geophysical Surveys	$100K - $500K	4 - 12 months	May be concurrent with other activities
Temperature Gradient Drilling	$20K - $300K per hole; $100K - $1.5 million for typical program of 5 - 15 holes	6 - 12 months	
Deep Exploratory Drilling	$500K - $3,000K per well; $1,000K to $5,000K for typical program of 2 - 4 wells	6 - 18 months	Time estimate assumes no permitting difficulties
Feasibility Assessment	$50K - $200K	2 - 6 months	

Development (Wellfield Only)

Activity	Cost Range	Time Required	Comments
Permitting / Planning	$100K - $300K	6 - 18 months	
Well Drilling	$1,500K - $4,000K per well	1 - 3 months per well, plus 4 - 8 months procurement	Total time and cost depend on project size
Well Testing (including interference)	$200K - $500K	4+ months	Time depends on project size
Evaluation (may include modeling)	$100K - $300K	6-12 months	

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Table 5.2: Estimated Budget and Time Requirements for Small (~5 MW) EGS Development

Exploration

Activity	Estimated Cost (K$)	Time Required (months)	Comments
Literature Search	20	2	Undertaken concurrently
Compliation of temperature data	20	2	
Evaluation of geologic and stress data	80	2	
Deep Temperature Gradient Drilling	1,200	6	Assumes 2-3 holes at $300 - $500K each; deeper than gradient holes for conventional geothermal projects; may not be needed if sufficient data are available from other sources
Feasibility Assessment	100	4	
Totals:	**1,420**	**12**	

Development (Wellfield Only)

Activity	Estimated Cost (K$)	Time Required (months)	Comments
Permitting / Planning	200	6	
Drill, core and log first well and undertake pre-stimulation injection test	7,000	3	Assumes well depth of 10,000 - 12,000 feet
Determine mechanical properties of cores, evaluate logs and plan stimulation of first well	150	3	Concurrent with next task
Set up seismic monitoring network	300	3	Concurrent with previous task
Stimulate first well and undertake post-stimulation injection test	1,000	1	After moving rig off
Evaluate stimulation and seismic monitoring data; site second well	250	2	Go / No-Go decision point (if Go, then begin power plant design)

Activity	Estimated Cost (K$)	Time Required (months)	Comments
Drill, core and log second well and undertake injection test	7,000	3	
Evaluate logs and plan stimulation of second well (if needed)	100	1	
Stimulate second well (if needed) and undertake post-stimulation injection test	500	1	
Undertake circulation and tracer test between the two wells	400	2	
Evaluate stimulation, testing and seismic monitoring data; site third well	150	1	Go / No-Go decision point (if Go, then begin power plant construction)
Drill, core and log third well and undertake injection test	7,000	3	
Evaluate logs and plan stimulation of third well (if needed)	100	1	
Stimulate third well (if needed) and undertake post-stimulation injection test	500	1	
Undertake circulation and tracer test between the three wells	400	2	
Evaluation and modeling	300	3	
Totals:	**25,350**	**33**	

Optional task