



Model for Success

An Overview of Industry-Military Cooperation in the Development of Power Operations at the Coso Geothermal Field in Southern California

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The Coso Geothermal Field, located in east central California (Fig. 1), hosts a world-class power-generating project that has been in continuous operation for the past 15 years. The project is located on the test and evaluation ranges of the Naval Air Weapons Station, China Lake—the Navy’s premier research and development (R&D) facility for air-to-air and air-to-ground ordnance. Fully financed by private investment, the Coso geothermal power project is a testament to creativity in business and government relations. At its peak, the project produced more than 273 megawatts (MW) of electricity that is all sold into the local utility grid under a long-term power sales agreement.

The geologic setting of the field is a releasing bend step-over in a dextral strike-slip fault system. Local crustal thinning accounts for the shallow (<2 km), very hot (200° - 328°C) resource. Given the present rate of production and reservoir projections based on historical data, it is anticipated that the field will be capable of producing electricity for at least 25, and possibly as many as 50 more years.

The overall military geothermal program is managed by the Geothermal Program Office (GPO) located at China Lake, CA. That office is located within the U.S. Navy, but has the broader mandate to oversee exploration for—and development of—geothermal resources wherever they occur on lands under the control of any of the nation’s military services. The GPO executes two broad functions: resource development and resource management. The entire program is guided by the underlying principal that mission integrity is paramount. Thus, if the mission of a candidate facility will be adversely impacted beyond mitigation, a geothermal project will not proceed. However, it has been found that most real or perceived impediments can be successfully resolved so that viable geothermal power projects can—and do—move forward.

Navy Unit 1 at the Coso Geothermal Field. Four geothermal power plants operated by Caithness Energy LLC (Reno, NV) at the China Lake U.S. Naval Air Weapons Station near Ridgecrest, CA produce 270 megawatts of electricity for the base and the California grid. TIC / GRC

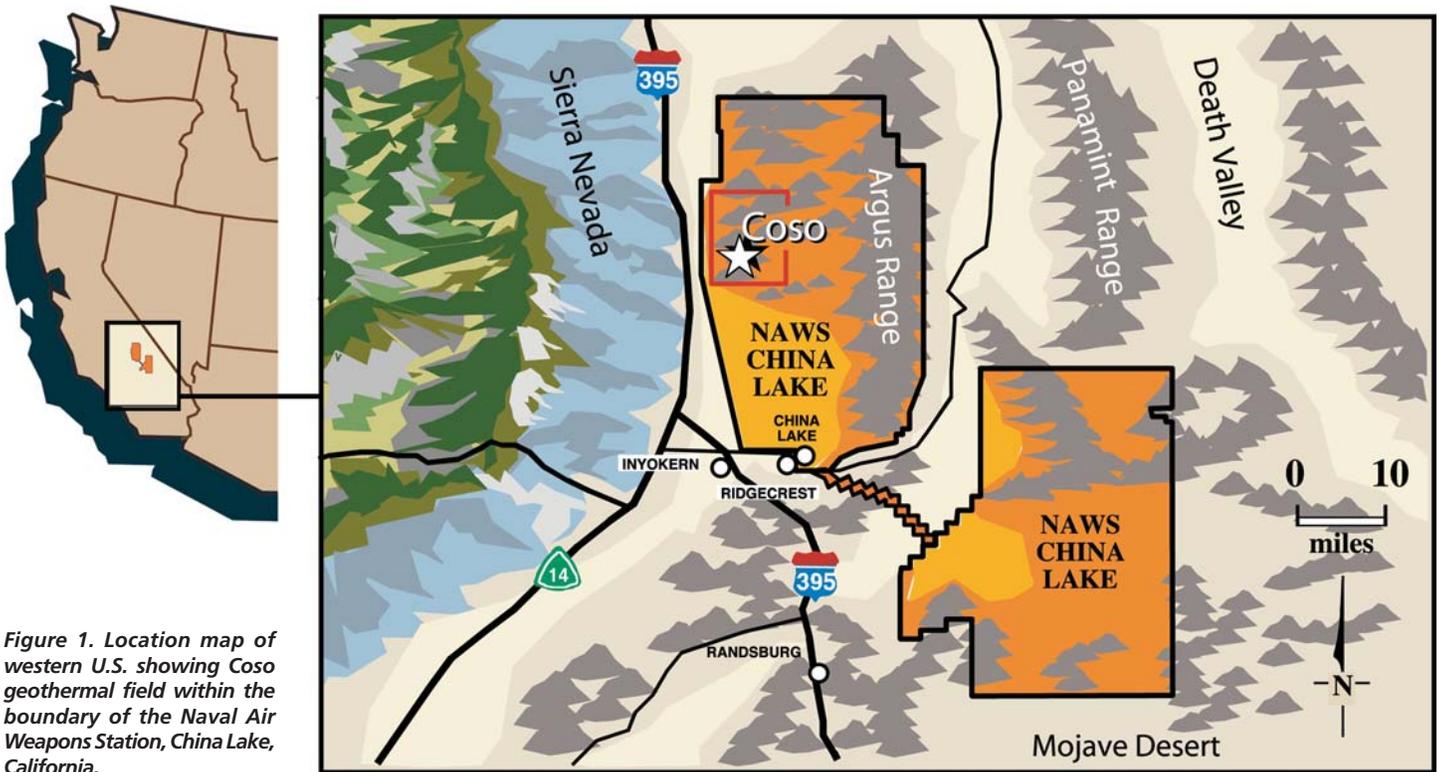


Figure 1. Location map of western U.S. showing Coso geothermal field within the boundary of the Naval Air Weapons Station, China Lake, California.

The Coso Field – A World-Class Resource

Four geothermal power plants with nine 30-MW (nameplate) turbine-generator sets are located within the main production area of the Coso Geothermal Field. The power plants were constructed from 1987 through 1990. The first unit went on-line in 1987, and the last units went on-line in early 1990. Unit 1 is a Mitsubishi Heavy Industries product, while Units 2-9 were manufactured by Fuji Electric Co., Ltd. Total electricity production from the field since 1987 is more than 26,000 gigawatt-hours (GWh), and the units have an on-line availability of more than 98 percent.

Relatively high temperatures (200° - 328°C) within the field permit use of double-flash technology for steam extraction. Wellhead pressures range from 500 psig to 85 psig (low pressure). Production waters are considered moderately saline chloride brines with total dissolved solids ranging from 7,000 ppm to 18,000 ppm. Non-condensable gases make up six percent of the gas fraction, with 98 percent of that amount being carbon dioxide. Hydrogen sulfide is in the range of <10 ppm to approximately 85 ppm.

The geothermal field is principally a liquid-dominated system, though there is production in the form of single-phase gas and single-phase liquid in different parts of the field. Over the past 15 years, we have found that the geothermal system is liquid limited not heat limited. Thus, the boiling interface has been systematically dropping despite the fact that all available fluid has been injected into the field since the outset of production. At any given time, there are approximately 80 to 90 production wells that feed more than 14 million pounds of mass per hour into the system. Each turbine-generator set requires one-half million pounds per hour of steam to operate at maximum capacity. Spent brines and conden-



A \$10-million deep delineation geothermal drilling project at Coso may result in new geothermal power production potential.

sate are injected either through infield wells or wells located along the margins of the field. Approximately 30 to 40 wells are used for injection at various times, depending on how much fluid must be handled and where pressure support is required.

Location and Geologic Setting

The Coso Geothermal Field is located in the central Coso Range, which is part of the triangle-shaped area known as the Southwest Basin and Range Geographic/Geologic Province (Fig. 2). The area is bounded by the Walker Lane on the northeast, the Garlock fault on the south, and the Sierra Nevada Range on the west. The site is approximately 160 miles north-northeast of Los Angeles, CA in a highly active seismic zone along the eastern margin of the Sierra Nevada. It is totally within the boundaries of the Naval Air Weapons Station, China Lake, which presents some unique operating circumstances and opportunities.

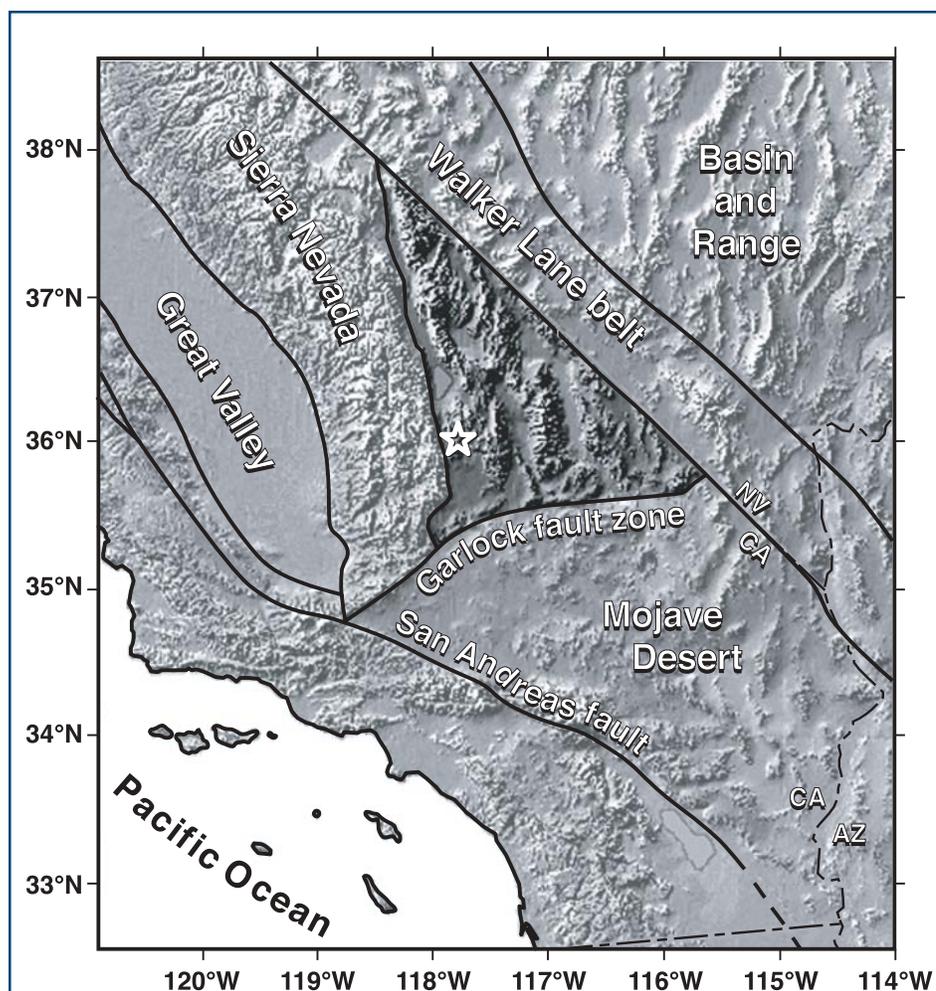


Figure 2. Shaded relief map of the area of interest showing major geographic provinces. Star indicates location of the Coso Geothermal Field. Note the triangle-shaped area created by the Walker Lane on the northeast, the Sierra Nevada on the west, and the Garlock fault on the south. This block, sometimes referred to as the southwestern Basin & Range, is believed to be a microplate forming between the North American and Pacific plates (Monastero et al., 2000).

As shown in Figure 3, the structural setting of the geothermal field is a releasing bend step-over in a dextral strike-slip fault system (Monastero et al., 2000). The step-over is bounded on the southwest by the Little Lake fault system, and on the northeast by an unnamed fault in lower Centennial Flat that continues northwestward to form the eastern margin of Owens Lake. The Airport Lake fault is a cross-basin fault that plays a very important role in determining the location of the geothermal production area itself. It extends diagonally across the entire step-over and is the locus of maximum crustal extension within the Coso Range itself.

Using global positioning system technology, we have measured the crustal velocity across the Coso Range over the past eight years and found that there is an average of 6.5 mm/yr of dextral offset between the Argus Range to the east and the Sierra Nevada to the west. The steps occur in 2 to 2.5 mm/yr increments, and are associated with specific, known faults. A consequence of this fault

geometry is the fact that crustal thinning must be accommodated within the structure. Evidence of this crustal thinning is found in the shallow seismic-aseismic boundary, and the chemistry of the rocks and fluids.

The Coso geothermal reservoir is entirely within Mesozoic plutonic and metamorphic rocks similar in nature to those found in the southern Sierra Nevada. They range in composition from leucogranite to gabbro, including a unique petrologic occurrence—the mixed complex (Whitmarsh, 1998)—which is an intimate mixture of two apparently immiscible melts, one felsic and mafic. In-house work performed by the GPO shows that the geothermal reservoir does not appear to be associated with any specific rock type. Rather it is an accidental host for the hot fluids. The controlling factor seems to be fracturing caused by modern tectonic forces.

Initial comprehensive geologic mapping of the area was done by Duffield and Bacon (1980), who focused on the volumetrically smaller Cenozoic volcanic rocks that occur as a thin carapace. This suite has an average thickness of less than a few tens of meters over the Mesozoic basement. The total estimated volume of volcanic rocks is ~35 km³. These authors identified two separate periods of volcanism with distinctively different characteristics: a middle to late Pliocene period, and a Pleistocene/Holocene period.

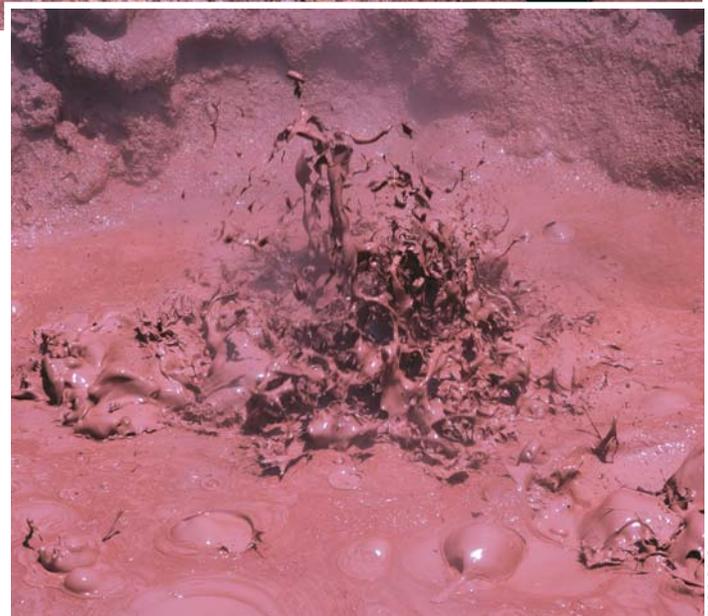
The Pliocene outbreak lasted from 4.0 Ma until approximately 2.5 Ma, and is represented by the entire gamut of lava flows and pyroclastic rocks ranging in composition from basalt to rhyolite, but all belonging to a calc-alkaline suite. These rocks oc-

cur principally in the eastern part of the Coso Range in an area known as Wild Horse Mesa, though small outcrops also occur in the central part of the range. The Pliocene volcanic rocks represent approximately 88 percent of the total volume of extrusives found in the Coso area (Duffield et al., 1980). In spite of the fact that they are not the source of heat for the modern geothermal field, these Pliocene volcanic rocks played an important role in determining the location of the field today due to strain softening of the crust.

The Pleistocene/Holocene volcanic rocks are more limited in area, occurring principally in the central and southern Coso Range. They only make up ~12 percent of the total volume of volcanic rocks in the range, are distinctly bimodal in nature, and range in age from ~2 Ma to 39,000 years old (Duffield et al., 1980). This latter age is somewhat suspect because of the unreliability of the K/Ar or the $^{40}\text{Ar}/^{39}\text{Ar}$ radiometric methods for rocks this young. Compositionally, the Pleistocene/Holocene volcanic rocks are either high-silica rhyolite or basalt, and they are found in separate areas with little overlap. The rhyolites occur in the central part of the Coso Range mostly as thirty-two separate pumiceous, perlitic, endogenous domes. There are very limited occurrences of nearly aphyric rhyolite lava flows, and silicic pyroclastic material is in the form of ash-flow tuffs, block and ash flows, and air fall tuffs filling the topographic lows between domes. There is only one occurrence of a well-preserved tuff ring that presumably surrounds the youngest domes in the field (Fig. 4).

The basaltic rocks occur mostly as flows in the southern and western parts of the Coso Range, though there is a significant amount of pyroclastic material associated with the flows. The youngest of these flows emanates from a location known as Volcano Peak at the southern end of the Coso Range. This flow is dated at 39,000 years, but this date is highly uncertain because of the sensitivity limits of the dating method.

Isotope analysis of the Pleistocene-Holocene rocks show that they have unusually low $^{40}\text{Sr}/^{39}\text{Sr}$ ratios and unusually high e-neodymium values (Monastero et al., 2000; Groves, 1996). When taken together, these data indicate that the rocks originated from fractional crystallization of an asthenospheric parent, not from crustal contamination of a mafic parent. The significance of this observation is that sometime in the recent geologic past, there has been underplating of mafic magma derived from asthenospheric material beneath the Coso geothermal area, or mafic dikes derived from asthenospheric magma have been intruded at relatively shallow depths. These “fresh” magmas provide the heat engine for the geothermal resource.



The youthful character of the Coso geothermal system is evidenced by hot springs, mud pots, mud volcanoes and fumaroles covering a nearly 2,600-hectare area.

Because Coso is situated within an active releasing bend structure, we believe that this underplating is also an ongoing process. This theory is consistent with the observation that the field is apparently not heat limited. In fact, work done by Manley and Bacon (2000) showed that the field has actually increased by an average of 30° C over the past one million years, and the magma source has been migrating upward from a depth of 10 km to as shallow as 5 km. These observations, too, are consistent with a youthful geothermal system.

U.S. Geothermal Development

Further evidence of the youthful character of the Coso geothermal system is found in the thermal features that abound in the area. Hot springs, mud pots, mud volcanoes and fumaroles cover a nearly 2,600-hectare area, indicating an extensive, active, near-surface resource. These features vary considerably in surface activity as might be expected in natural systems, though the causes of such variability are poorly understood. Such is the case with surface thermal features in New Zealand (Browne et al., 1994), where there is also a considerable amount of both temporal and spatial variability. Hunt and Bromley (2000) show that there was a direct correlation between geothermal fluid production and cessation of activities at nearby surface thermal sites in New Zealand, but they were very localized. Some of those sites increased in activity, while some of them ceased to exist.

Instead of drying up and disappearing as was discussed in the Final Environmental Impact Statement for the Coso project (Dodson et al., 1979), surface thermal features at the Coso Hot Springs area increased in activity after production commenced in the nearby Navy I well field. To date, there has been no irrefutable evidence connecting the two phenomenon, but the close temporal relationship calls for a more thorough investigation of a possible cause-and-effect relationship. The Coso Hot Springs area is considered to be sacred to the local Native American Paiute and Shoshone tribes, and is protected from exploitation under an agreement with the California State Historic Preservation Office.

Coso Project History

The Coso geothermal project was the brainchild of Dr. Carl Austin who, as a research rock mechanics scientist at China Lake, recognized the huge potential of the resource. In the early 1960s, Dr. Austin began a campaign of convincing the Navy that it was in their best interest to develop the geothermal resource, despite the fact that such an activity was not part of their fundamental mission. The major issue was encroachment management, a topic that pervades the decision-making process of the military regardless of the project. A second, equally important part of the campaign was convincing anyone who would listen that there was a viable geothermal resource located beneath the Coso Range. In particular, the U.S. Geological Survey believed that the resource was too small to support an economically meaningful project. Finally, Austin had to convince industry that the Navy was an entity with which they could do business.

By 1977, a full-scale scientific and engineering investigation of the Coso geothermal resource was underway with the drilling of 17 heat flow holes, acquisition of large amounts of geophysical and geological data, and drilling one deep test

hole. The results of those efforts, summarized in a special volume of the *Journal of Geophysical Research* (1980), substantiated the existence of a large, viable geothermal resource at Coso and set the stage for future development. The 1,476-meter deep test hole proved that commercial temperatures and fluid flow rates were possible, providing the springboard for a third-party contract with California Energy Co. Inc. (then located at Santa Rosa, CA), which was executed in December 1979.

The first successful production well was completed in December 1981, and was declared a success by, then-Secretary of the Navy, John F. Lehman on Jan. 19, 1982. Subsequent reservoir testing showed that production capacity was in excess of 30 MW. No one involved with the project suspected at the time that the ultimate capacity would be more than 270 MW.

Between 1981 and 1987 when the first power generating unit (Navy I, Unit 1) came on line, issues regarding financing, power sales, and revenue sharing were resolved. On July 15, 1987, the first electricity from the Coso project was delivered to the South-

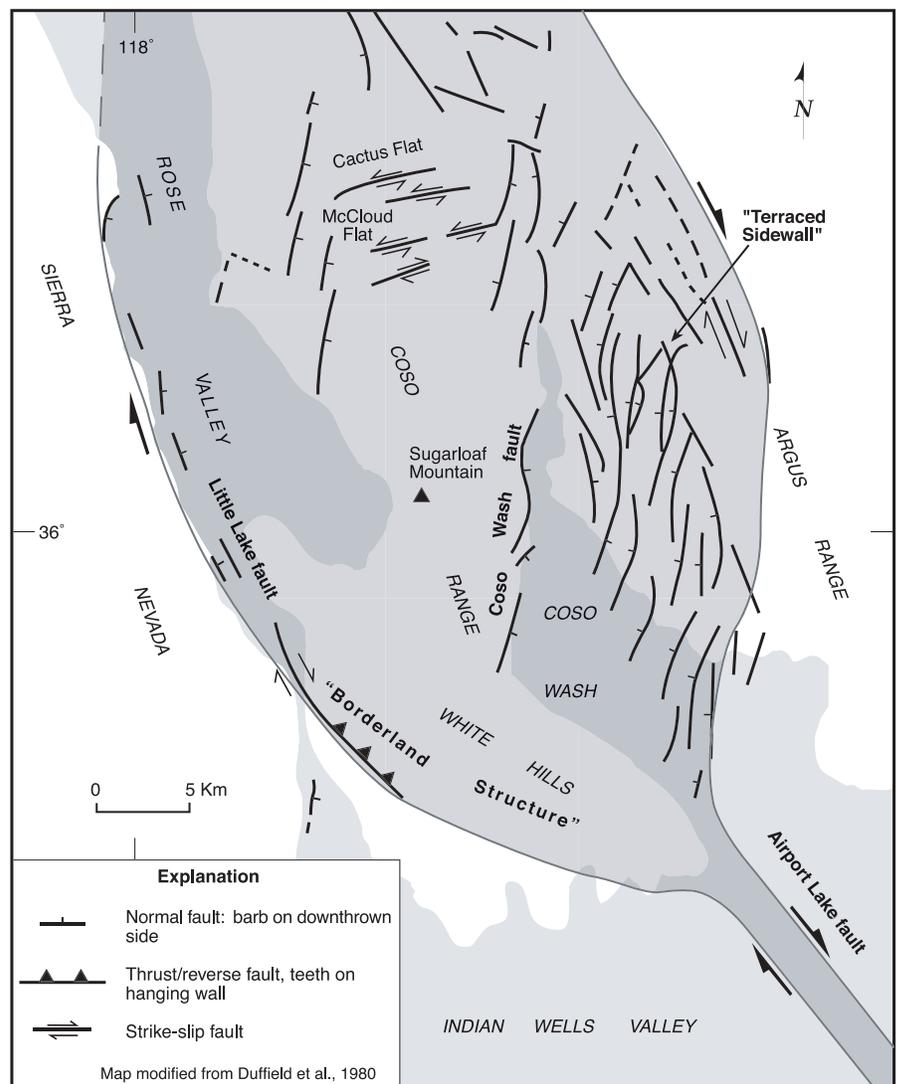


Figure 3. Structural geology map showing the releasing bend geometry of the Coso Range.

ern California Edison power grid. Subsequent drilling confirmed an even larger resource than was first thought, giving rise to construction of eight more units and boosting the total output capacity to 270 MW. Since, January 1990 when the last of the units was brought on line, average on-line availability of the Coso geothermal power plants has been 98 percent with a record production of 2,318 GWh in 1995.

The Military Business Model

The business model used by the GPO is based on a time-tested and accepted concept of “farming-in,” which was developed more than five decades ago by the oil and gas industry. The approach is based on the premise that when front-end, high-risk exploration is done by a company at their own expense, they may decide for one reason or another that the prospect does not meet their economic criteria. So, they seek a partner who is willing to make the investment, and they take an overriding interest in the play. Agreements between the parties are fully negotiated, taking into consideration how much was put into the delineation phase, current market conditions, and current/projected operating expenses. In short, if the economics of a project do not “pencil out” favorably, no deal will be struck.

There are a number of reasons why the Navy has adopted this type of model. First, and probably most important, it lowers front-end risk and facilitates securing of project financing without a large

initial capital outlay by the geothermal developer. Second, it is a model with which the industry is familiar. Third, it encourages development and exploitation of renewable resources—something that is required by U.S. Department of Defense policy—by providing pre-investment knowledge developed by the GPO. Finally, it cuts down dramatically on the likelihood of fruitless encroachment by speculators who secure the developmental rights, but don’t have the capital to conduct the requisite technical investigations to prove the resource. Their presence on a military facility represents encroachment that must be managed, but with no value.

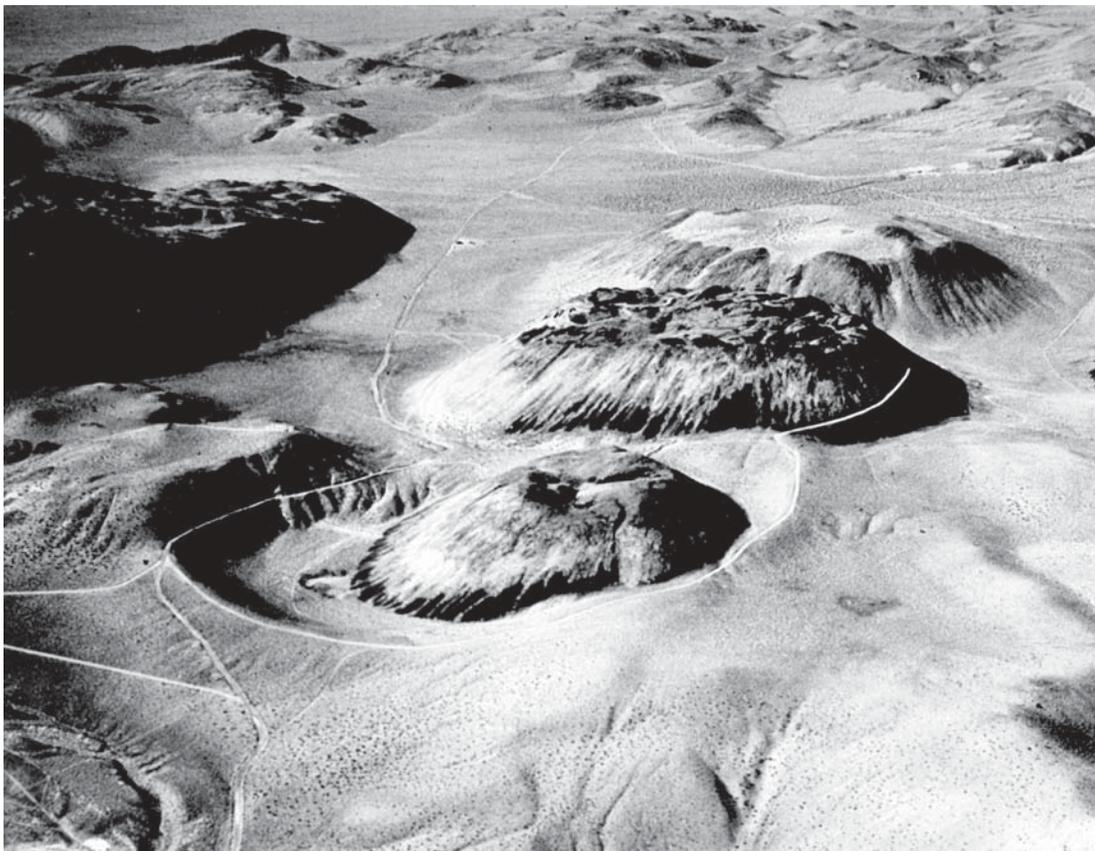
In his study of factors that affect investment costs for geothermal power plants, Stefánsson (2002) states that reconnaissance, surface exploration, and exploration drilling are responsible for adding three years to the front-end development time of geothermal prospects. The Navy approach minimizes or eliminates that period, and shortens the time from agreement to first power delivered.

Future Prospects on Military Lands

The GPO has identified more than 25 locations on military controlled lands that are prospective for geothermal development in the continental U.S. A thorough assessment of the full potential of those sites has just been undertaken, and is expected to be completed by the summer of 2003. In the meantime, the Navy is seeking a third-

party developer for its proven prospect at Naval Air Station Fallon (Nevada) where a resource has been drilled and tested.

Combs et al. (1995) estimate that the reservoir is capable of supporting a minimum of 30 MW of power generation based on the successful flow testing of a 2,195-meter deep test well and analysis of associated geophysical data. Recent exploration efforts by the GPO at the U.S. Army Hawthorne Army Ammunition Depot in Hawthorne, NV have shown there is potential there for development of its moderate-grade (150° - 200°C) geothermal resource. Plans are being made to conduct a reflection seismic survey to delineate the fault system that controls the Hawthorne resource, and to drill an intermediate-depth hole to test the resource. This work is expected to be complete by the end of 2003.



U.S. Navy

Figure 4. Photograph of the youngest rhyolite dome in the Coso field (in the foreground). Note the well-preserved explosion crater and tuff ring. This dome has been emitting steam from fissures on the summit since December 1999. Temperatures at a depth of 50 cm below the surface are in excess of 100°C.

Historical Perspective Coso Hot Springs Resort

The earliest written record describing Coso Hot Springs dates to 1860, when a miner at nearby Silver Peak named M.H. Farley mentioned “boiling hot springs to the south.” An 1881 survey of the area by the U.S. government noted “thousands of hot mud springs of all consistencies and colors,” and early maps show “Hot Sulphur Springs” at the location referred to today as Coso Hot Springs.

In 1895, William T. Grant was deeded a quarter interest in the Coso Hot Springs area, and by 1909, had established a health resort there. The first documented owner and proprietor of the Coso Hot Springs Resort was Frank Adams, who lived on the site from 1912 until approximately 1920. Some believe that Adams was hired by Grant and his partner Dr. I.J. Woodin to manage the property that they actually owned.

Claims of medicinal value of Coso waters, mud, and steam ranged from cures for venereal disease to constipation. In 1917, an advertising brochure issued by the Owl Drug Co. announced availability of mud from Coso Hot Springs at the bargain price of “\$3.00 per jar”—a hefty sum for that period. Water was also bottled and sold bearing the promise of, “Volcanic Health and Beauty from Nature’s Great Laboratory.” The bottle bore the claim that it, “...is a vitalizing blood builder which aids digestion, destroys invading bacteria and is especially recommended in cases of gastritis, stomach and intes-



In the early 20th century, “sour” water from the Coso geothermal resource was bottled for sale, claiming “Volcanic Health and Beauty from Nature’s Great Laboratory.”

tinal catarrh. The water acts directly upon the liver and kidneys, thus eliminating toxic water, the neglect of which so often causes nervousness, high blood pressure and rheumatism. Recommended four doses daily.”

Clientele at the Coso Hot Springs Resort during the early years were primarily residents of nearby Rose Valley, Owens Valley, and a doctor from Santa Maria. Later visitors, able to take advantage of the newfangled “horseless carriage,” came from the Los Angeles Basin, San Bernardino, and as far away as San Francisco.

The resort remained in operation until 1943, when the U.S. Navy began purchasing land for their China Lake Naval Ordnance Test Station (forerunner of today’s Naval Air Weapons Station). By 1947, all land purchases had been completed and the Coso Resort Hot Springs—now located within the boundary of the Navy base—was permanently closed. (Edited from *A Land Use History of Coso Hot Springs, Inyo County, California*, Naval Weapons Center Administrative Publication 200, 1979, 233 p.)



Photos: U.S. Navy

A tourist at the Coso Hot Springs Resort collects geothermal water, hoping it would aid digestion and eliminate “nervousness, high blood pressure and rheumatism.”