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THE CERRO PRIETO AND SALTON SEA GEOTHERMAL FIELDS – ARE THEY REALLY ALIKE?

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ABSTRACT

In the Salton Trough, of southern California and northern Baja California, the most important geothermal fields are those at the Salton Sea (SSGF) and Cerro Prieto (CPGF). They have nearly the same geologic framework; both are located in active pull-apart basins within the Trough, an actively growing rift valley which is the northern landward extension of the Gulf of California. The lithologic columns in these fields are dominated by deltaic and alluvial deposits, with that of the SSGF being richer in lacustrine sediments and evaporites. The heat sources in both fields are oceanic ridge-type intrusions of sheeted dike complexes. The volcanoes found in the CP and SS areas are genetically related to the hypabyssal rocks intercepted by some of the geothermal wells. The maximum temperatures measured in the wells are similar (i.e., around 350-370° C).

The main difference between the two fields is in the salinity of the geothermal fluids. The maximum total dissolved solids in the SSGF geothermal brines is about 30% and only about 3% in CPGF brines. The hydrogeological regimes and the lithology prevailing in these fields could reflect this contrast.

In spite of their similarities, the difference in the rate of field development has been enormous. Although the SSGF was discovered earlier and seems to have a larger energy potential, the CPGF was developed faster, at present having more than twice the capacity installed at SSGF. This was largely due to the high salinity (and corrosivity) of the SSGF brines. It took intensive research to develop the technology to handle these brines at the surface, separate the steam for electrical generation, and inject the waste brine safely. Other important factors influencing field development were the dissimilar economic and regulatory conditions in Mexico and the US.

INTRODUCTION

In the Salton Trough, which includes the Imperial Valley (US) and the Mexicali Valley (Mexico), a number of geothermal areas were initially identified on the basis of surface evidence (i.e., hot springs, boiling mudpots and mud volcanoes, etc.), and anomalous high temperatures in water wells and exploratory oil wells. Beginning in the 1960s, geophysical surveys confirmed the existence of these and other geothermal areas (see for example, Rex et al., 1971; Fonseca et al., 1981).

The first long-lived commercial developments of liquid-dominated geothermal systems in North America took place in this region; i.e., in the Cerro Prieto geothermal field (CPGF) of Baja California in 1973, and in the East Mesa geothermal field (EMGF) of California in 1980 (CFE, 1992; DOE, 1997). At present the installed electrical generation capacity in the Trough exceeds 1,000 MW (i.e., in Mexico 620 MW at CPGF; and in California 248 MW at the Salton Sea geothermal field (SSGF), 105 MW at EMGF and 84 MW at the Heber geothermal field).

As is typical of all geologic systems, the Salton Trough geothermal areas have their own particular characteristics, but they also have some underlying similarities. Here we compare the CPGF and SSGF, the two largest and hottest (maximum reservoir temperatures 350-370°C) geothermal fields in the Trough, to highlight their similarities and differences from the earth sciences and developmental points of view.

The Salton Trough has a hot desert climate characterized by low precipitation, high evapotranspiration and extreme high temperatures. Most of the Imperial Valley is below sea level; most of the Mexicali Valley is above it. The SSGF is located in the Salton depression, a closed basin that is presently occupied by the Salton Sea, an inland saline lake whose surface is about 72 meters below sea level; the field extends under the Sea. On the other hand, the CPGF is at about 10 meters above sea level (masl).

The Colorado River enters the Salton Trough at an elevation of about 40 masl. The CPGF is south of the Colorado River delta (Fig. 1). Groundwaters south of the crest will flow toward the sea (i.e., Gulf of California), while those north of the crest, flow toward the closed Salton Sea depression, where they can escape only by evaporation. These flow directions are confirmed by Makdisi et al., (1982). It is of interest to note that during recent geologic times the location of Cerro Prieto with respect to the crest seems to have been similar to its position today. According to Waters (1983), the high stand of the Late-Pleistocene Lake Cahuilla occupying the depression may have extended from Palm Springs to just north of the Cerro Prieto area.

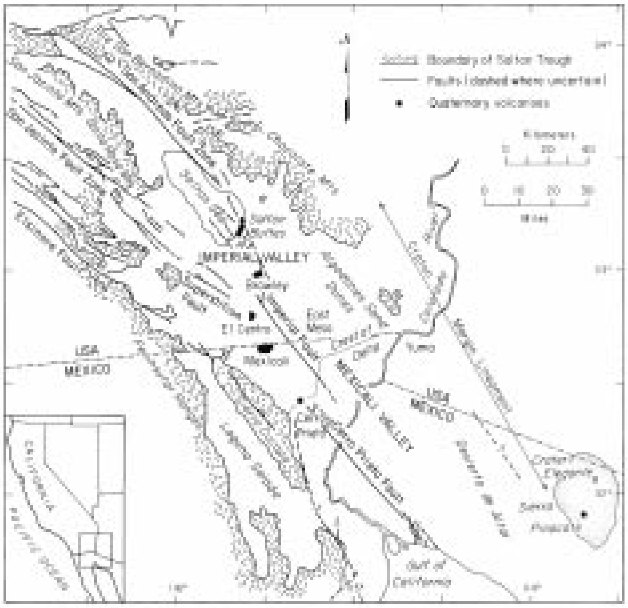


Figure 1. Regional geological model of the Salton Trough showing the location of the crest of the Colorado Delta (modified from Palmer et al., 1975).

The capacities of these fields are comparable, probably related to their similar heat sources. The ultimate electrical generation capacity at the SSGF should be much higher than the present 248 MW. Featherstone et al. (1995) estimate it to possibly exceed 1,000 MW. According to Hiriart and Gutiérrez (1996) the CPGF can support at least another 160-180 MW above the present installed capacity, for a total of 780 to 800 MW.

GEOLOGY

The Salton Trough is a large trans-tensional basin (Herzig and Jacob, 1994) that lies astride the Pacific-North American plate boundary over the 300 km distance between the southern end of the San Andreas fault near the Salton Sea and the northern end of the Gulf of California. This broad structural trough, characterized by high heat flow, tectonic deformation and seismicity, as well as volcanism, resulted from tectonic activity that created a series of pull-apart basins and transform faults linking the East Pacific Rise to the San Andreas fault system (Elders et al., 1972; Lachenbruch et al. 1985; Fig. 2).

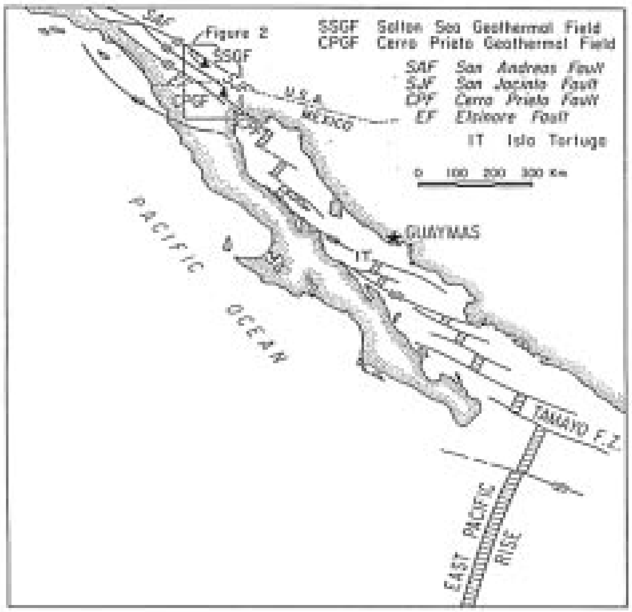


Figure 2. Generalized map showing the location of the Cerro Prieto (CPCF) and Salton Sea (SSGF) geothermal fields within the Salton Trough and Gulf of California tectonic regime (from Herzig, 1990).

The CPGF and SSGF are associated with two of these basins where the crust is being pulled apart by right-lateral, strike-slip fault movements (Lomnitz et al., 1970; Elders et al., 1972); the Brawley (California) geothermal field is thought to be in a third one. As the crust is pulled open, it thins and begins to subside forming basins that quickly fill with sediments.

Lachenbruch et al. (1985) conclude that the Salton Trough probably formed by distributed extension not confined to the present seismic zones and that the position of these zones of extension and seismicity (i.e., pull-apart basins) has changed over geologic time. Similarly, Newmark et al. (1988) suggest that the intense local thermal anomalies found in the SSGF are geologically short-lived; probably this also applies to other geothermal fields in the Trough.

Where thinning of the crust and basin development are rapid, upwelling of magma from the asthenosphere will occur, generating new oceanic-type crust. According to the model of Lachenbruch et al. (1985) the extended crust is being intruded by gabbroic magma from the mantle, while subsidence is accompanied by rapid sedimentation that keeps the ground surface near sea level elevation and isostatic balance prevails. The rifting and igneous intrusions explain the high heat flow and high temperatures observed at shallow depths in the Trough. Wells drilled in the SSGF and CPGF have intersected hypabyssal rocks, their fluids show high $^3He/^4He$ ratios, and volcanoes are found nearby (Herzig and Jacob, 1994; Lippmann et al., 1997; Mack Kennedy, pers. comm., 1998).

During the early Pliocene, approximately 4 to 5 million years ago (Ma; Herzig and Jacob, 1994), the current configuration of the Gulf of California began to take shape as major crustal extension split Baja California from the Mexican mainland. At that time, the waters of the Gulf extended northward to about, and perhaps beyond, the present Salton Sea area.

The advance of the Colorado River delta into the Cerro Prieto area began in the mid-to-late Pliocene (2-3 Ma). The closure of the marine connection between the Gulf of California and the Imperial Valley was complete by the late Pliocene. This resulted in the conversion of the Salton depression to a continental depositional basin (Lyons and van de Kamp, 1980; Ingle, 1982; Halfman et al., 1985). South of the delta (i.e., in the area of the CPGF) the partial influence of the marine environment has continued to the present, with deposition of Colorado river sediments becoming predominant during the Quaternary.

The subsurface stratigraphy of the Salton Trough is characterized by vertical and lateral variation in lithofacies. The lithologic column consists of an upper part of poorly indurated sands, silts and clays, and a lower part of sandstones, claystones and siltstones. The hydrothermal alteration of the deeper layers and the existence of hydrothermal mineral zonation around and within the geothermal reservoirs have been documented by careful mineralogical studies of well cuttings and cores (e.g., Elders et al., 1981; Younker et al., 1982; Cho et al., 1988).

Sediments of nonmarine origin predominate at the SSGF. Lacustrine shales and siltstones are the dominant lithologies. There are sandstones which were deposited in lake margin, meander-channel fill, and lacustrine delta environments. The presence of stratabound sulfides suggests periods of brackish water conditions. Evaporites (common in the shales), bedded anhydrite and mudcracks record periods of subaerial exposure and desiccation in a sabkha-like environment (i.e., areas of evaporation and saline infiltration). The interbedding of lacustrine muds, coastal sand deposits, and evaporite-bearing muds was probably controlled by fluctuations in paleolake levels and periodic flooding of the Salton Sea region by the Colorado River, followed by periods of desiccation (Herzig et al., 1988).

On the other hand, the lithologic column at CPGF shows only minor amounts of evaporites and sulfides (mainly pyrite and pyrrhotite). The deeper part of the column was deposited in a coastal deltaic environment (Lyons and van de Kamp, 1980: Halfman et al., 1985). Shallower deposits are mainly related to the Colorado River delta. That is, at CPGF the marine influences are stronger than at SSGF.

The age of the CPGF is not well constrained. Herzig (1990) infers that the hypabyssal rocks encountered by some of the geothermal wells, which seem to be related to the heat source of the geothermal systems, are most likely of Quaternary age (i.e., less than three million years old). On the basis of paleomagnetic data, de Boer (1980) indicates that the CP volcano originated about 0.11 Ma and continued to be active intermittently until about 10,000 years ago.

Kasameyer et al. (1984) suggest that the age of the SSGF ranges from 3,000 to 20,000 years; i.e., the hydrothermal system is very young. This seems to be confirmed by the work of Newark et al. (1988).

CONCEPTUAL MODELS OF BRINE ORIGINS BASED ON GEOCHEMISTRY

Brines in the high-temperature zones of the SSGF and CPGF differ greatly in composition, as can be seen in Table 1 and Figure 3. In the table, SS hypersaline brine is represented by a sample (3-1986) collected from the Salton Sea Scientific Drilling Project (SSSDP) well State 2-14 chosen because it has relatively high concentrations and includes some trace element analyses (Williams and McKibben, 1989). Data for well M-5 in 1977 of the CP Alpha reservoir (Truesdell et al., 1981) was used in the table rather than analyses of well fluids from the deeper, hotter and more productive Beta reservoir because trace element data were available. Along with these analyses, the table and figure contain analyses of standard seawater (Goldberg, 1965) and brine from Reykjanes well 8 (Arnorsson, 1978) which clearly was derived from nearby seawater.

Figure 3 is a Schoeller plot in which each line represents an analysis, and analysis lines with parallel segments between two constituents have the same ratios of these constituents. From this figure (and Table 1) it can be seen that the SS brine is about 10 times more concentrated than the CP brine in all constituents except for Mg and Ca (SS>CP by 100 times), Br (SS>CP by 3.5 times), and SiO_2 (SS ≈ CP). CPGF and Reykjanes fluids are similar to seawater in Na, Ca, Cl and Br but much higher in Li and K, and much lower in Mg and SO_4. These chemical differences between seawater, and seawater geothermally altered at about 300°C, result from deposition of anhydrite ($CaSO_4$), incorporation of Mg in chlorite and possibly dolomite, and exchange of Li and K in minerals for Na in the brine. Additional Ca is contributed by albitization of plagioclase. These mineralogical changes have been documented in coastal geothermal systems and by hydrothermal alteration experiments (references in Truesdell et al., 1981).

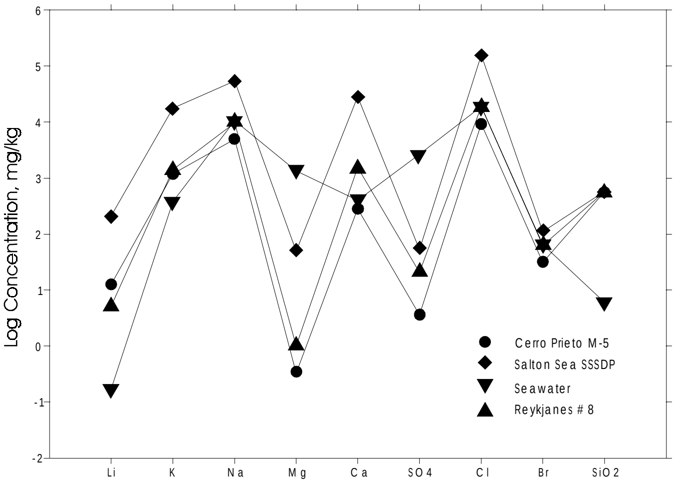


Figure 3. Chemical compositions of aquifer fluids from Cerro Prieto well M-5, and Salton Sea SSSDP well State 2-14 compared to those of normal seawater and Reykjanes well 8 (geothermal fluid compositions calculated for reservoir conditions)

The near identical Cl/Br ratios (297 ±5) of seawater and CPGF and Reykjanes brines suggest that these elements are not affected by rock reactions at about 300ºC and provide further evidence that both of the geothermal samples were derived from seawater.

This is obvious for the Reykjanes water which has an $\delta^{18}O$ value (-0.22‰) close to that of seawater

Table 1. Compositions of standard seawater and some saline geothermal waters, including SSSDP well State 2-14, Cerro Prieto well M-5 and Reykjanes well #8 (concentrations in mg/kg; geothermal waters calculated to reservoir conditions).

Source	Na	K	Mg	Ca	Cl	Br	SO_4	B	SiO_2	δD	$\delta^{18}O$	CO_2	H_2S	T (°C)
SSSDP 2-14	54800	17700	49	28500	158000	111	53	271	580	-70	1.5	1580	10	330
CP M-5	5000	1200	0.33	284	9370	31	3.6	10.5	569	-95.5	-8.32	2400	180	300
Seawater	10500	380	1350	400	19000	65	265	4.6	6	0.0	0.0	100	-	4
Reykjanes#8	9630	1410	1.0	1550	18800	63	21	9	572	-22	-0.26	1930	45	283

(although for reasons not yet fully understood δD is lower at -22 ‰). However, the deuterium concentrations of CPGF waters (δD = -94 to -98‰) are much closer to that of Colorado River water (δD = -107 ±2 ‰) than to that of seawater (δD = 0‰), and the δ^{18}O values of CPGF waters (-8 to -10 ‰) are only about 6 ±1 ‰ higher than that of the river water (near -15 ±0.5 ‰) due mostly to oxygen isotope shift.

Truesdell et al. (1981) argue that a hypersaline marine brine was formed in coastal lagoons similar to the modern sabkhas of Israel and the Persian Gulf. In these brines the Cl/Br ratio of seawater was preserved, indicating that evaporation did not proceed to the precipitation of halite (which would have changed the Cl/Br ratio as Br was washed away). Part of these hypersaline brines migrated to the bottom of the sediments in the southern part of the Salton Trough. This downward migration occurred because the hypersaline brines had much higher densities than the river waters saturating the sediments. When the pull-apart basin moved to the location of the CPGF, heat injected into the deep brines caused them to rise up through sediments containing riverwater and mix to varying degrees with this water. Both enthalpy-chloride and δD-chloride diagrams show mixing between Colorado River water and a hot saline end member consistent with an evaporated marine hypersaline brine with ~110,000 ppm Cl and +20‰ δD, like those found in modern sabkhas (Truesdell et al., 1981).

This model is similar to those suggested for the origin of the SS hypersaline brines by White (1968, 1981) and Rex (1972, 1983, 1985) except that, at the Salton Sea, the infiltrating hypersaline brines come from evaporation of Colorado river water rather than seawater. This evaporation presumably took place in the numerous successive closed basin lakes that preceded the modern Salton Sea. The Cl/Br ratio of the SS geothermal brines (1420; Table 1) is similar to those of Colorado River waters below Hoover Dam (1500 to 1900; Rex, 1972). These high Cl/Br ratios are typical of continental brines formed from solution of evaporites (Rex, 1972). The Cl/Br ratio of the infiltrating hypersaline brine would be preserved so long as most halite deposited during evaporation in the closed basin lakes was redissolved by succeeding lakewaters or by infiltrating brine. Thus, a continental rather than marine origin is indicated for The SSGF brines. The low deuterium content of the SSGF brine (-70 to -75 ‰; Williams and McKibben, 1989) is not understood, but may indicate some mixing with Colorado River water or an origin from solution of recently formed evaporites by partially evaporated river water. The suggestion by McKibben et al. (1988) that deep solution and thermal metamorphism of evaporites contributed to the brine is basically consistent with the earlier theories cited.

Based on the composition of brines from the CPGF and SSGF, it appears that the bottom of the Salton Trough is likely to be occupied by hypersaline brines. The continental brine in the northern part of the Trough is more concentrated than the marine brine in the southern part. In the north, the hypersaline brine was formed in closed basin lakes or by solution of salts formed in these lakes. In the south, the edge of the delta was periodically occupied by evaporation basins (sabkhas) where concentrated brines could form and infiltrate into the underlying sediments. The ephemeral character and limited size of these basins produced brines that were less concentrated and more limited in volume than those in the north.

There are some interesting differences between the SSGF and CPGF brines. Although the temperatures of alteration and the mineral suite produced are similar, clearly other factors are responsible for the much higher concentrations of Mg, Ca and SO_4 in the SSGF brine. If the equilibrium precipitation of chlorite required a particular concentration of Mg and the precipitation of anhydrite required a particular product of Ca and SO_4 concentrations, then these values should be found regardless of the total salinity. Inspection of the data indicates that this is not the case. The Mg concentration in SSGF brine is about two orders of magnitude higher than in CP or Reykjanes waters. Similarly the product of Ca and SO_4 concentrations is almost two orders of magnitude higher than in the more dilute brines. These differences are caused by the chemical behavior of solutes in highly saline waters compared with their behavior in dilute waters. The quantities effective in mineral precipitation are in fact "activities" rather than concentrations. As salinity and temperature increase, activities are affected by complexing and generally decrease. Williams et al. (1989) have calculated using computer code EQ3/6 that some waters from the SSGF and CPGF are saturated with respect to anhydrite, but their study does not include chlorite.

Compared to the CPGF production fluids, the SSGF brine is much lower in H_2S and much higher in Cl (Table 1). This allows base and precious metals that form stable chloride complexes to be carried in solution (McKibben et al., 1988). At Cerro Prieto metal concentrations in solution are much lower, although some metal sulfides are deposited in the reservoir. The presence of metals in the SSGF brine has given rise to several schemes for their commercial recovery (see Gallup, 1995 and references given therein). Some trace element analyses of the CPGF and SSGF samples are given in Table 2.

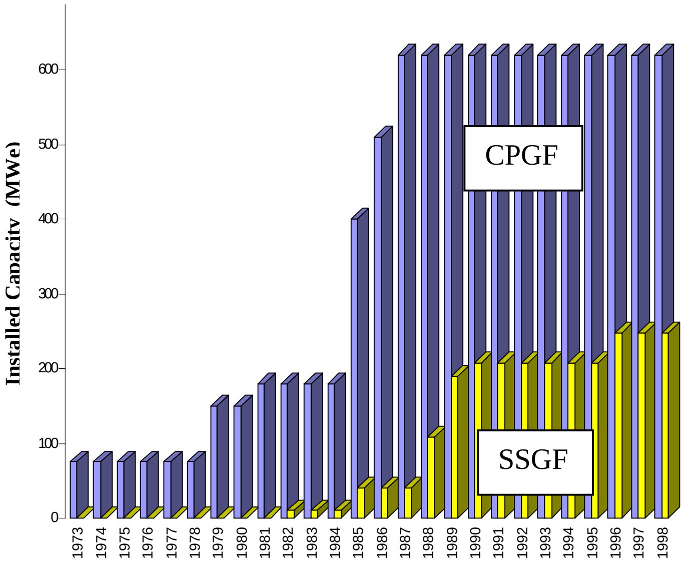
DEVELOPMENTAL HISTORY

Geothermal exploration in the Cerro Prieto area started in the late 1950s and led to drilling the first deep exploration wells in 1960-61. Drilling techniques used in these wells were adopted from the oil industry. Due to the high temperatures, drilling muds tended to solidify in the well, so a cooling tower was installed to lower the temperature of the slurry. Frequent circulation losses through fractures and other permeable zones were encountered. A serious problem with casing collapse occurred as over forty percent of the early (pre-1972) well casings failed (Domínguez and Sánchez, 1978; Domínguez and Vital, 1979). Upgrading the steel metallurgy gradually solved this problem along with careful supervision of the cementing between the casing and the formation.

Early drilling efforts in the SSGF encountered similar problems, along with severe corrosion from the high salinity and dissolved gases in the geothermal fluids. After years of testing, methods were developed to prolong the life of production well casings. These were the installation of liners composed of corrosion-resistant metal alloys (including titanium), lining steel casings with cement, and the periodic replacement of thick-walled sacrificial steel liners before catastrophic corrosion failure occurs (Love et al., 1988).

Because of the generally unconsolidated reservoir formations at CPGF, most wells are completed with a slotted liner. At SSGF most wells are completed open hole due to the consolidated nature of the producing formation.

The Comisión Federal de Electricidad of Mexico (CFE) — which operates and manages CPGF — began power production in 1973 with 75 MW; by 1979, capacity was 150 MW and by 1981, 180 MW. At the end of 1986, by extending the area of production and completing two 220-MW plants, the total installed capacity reached 620 MW and remains so today (Fig. 4). Expansion to 720 MW by the year 2000 is planned.



(Data from CFE, 1992, DOE, 1997)

Figure 4. Developmental history for the Cerro Prieto and Salton Sea geothermal fields.

Initially, CFE justified the development of the CPGF by its favorable location and economics. Before CPGF was generating electricity, the northern part of Baja California relied mainly on an oil-fired power plant at Rosarito and it was necessary to transport oil by tanker from the Gulf of Mexico. Any failure in this plant originated blackouts and affected the local economy. When CPGF was put on production and connected to the Tijuana-Mexicali grid there were fewer power interruptions (CFE, 1971). From 1987 to 1996, CFE sold 220 MW to California utilities. Now, all the electricity being generated is needed to

Table 2. Some trace element analyses of brines from SSSDP Well State 2-14 and Cerro Prieto well M-5 (samples as in Table 1). Data are in mg/kg.

Source	Li	Rb	Cs	Mn	Fe	Zn	Cu	Pb	Cd	As
SSSDP 2-14	209	132	142	1500	1710	507	6.8	102	2.3	5
CP M-5	12.6	5.3	0.9	0.65	0.22	0.075	0.008	0.023	<0.008	0.25

satisfy the demand of the growing population and industrialization of northern Baja California, especially in Tijuana and Mexicali.

Exploration of the SSGF area to evaluate its electrical generation capacity began in 1927, much early than in Cerro Prieto (Signorotti and Hunter, 1992). Even though a small power plant operated at SSGF for a few months in 1959 (Palmer et al., 1975), it was not until 1982 that the first commercial plant of 10 MW (Salton Sea Unit 1) began generating (Fig. 4). At that time the first Cerro Prieto power plant had been on line for nine years. The delay in installing a power plant at the SSGP was due mainly to the high salinity and corrosivity, although public policy and economic considerations were also factors. An intensive research effort by industry and DOE slowly developed the technology to handle these brines at the surface, separate the steam for electrical generation and inject the waste brine safely back into the reservoir (Signorotti and Hunter, 1992).

Even though the maximum depths and temperatures of the reservoirs are similar, the amount of total dissolved solids (TDS) in the SSGF brine is ten times greater than at CPGF. Due to similar reservoir temperatures, the dissolved silica concentrations in the brine of both fields are almost equal. However, the high TDS of the Salton Sea brine caused rapid precipitation of silica scale and confounded early attempts of development.

This rapid precipitation caused scaling in the surface production lines and turbines. DOE-sponsored research developed a crystallizer/clarifier process in which the silica in the brine crystallized on seed crystals of silica previously precipitated. Thus silica in the effluent brine was sufficiently reduced to eliminate clogging of injection wells. Finally, a combination separator and crystallizer eliminated the problem of deposition throughout plant piping to the point of discharge of the clarifier (Signorotti and Hunter, 1992).

However, the size of the crystallizer/clarifier limited the power that could be produced and more recently a pH-modification process has proved to be an effective alternative for stabilizing the brine before injection. By adding hydrochloric acid, and sometimes a reducing agent, silica (and iron silicate) are kept in metastable solution. The pH modification method, unlike the crystallizer/clarifer, which has inflexible flow requirements, can adapt to changes in flowrate and is appropriate where the electric load is required to follow the demand (Hoyer et al., 1991).

During the early developments of the SSGF the effluent was sent to evaporation ponds, as was the practice at the CPGF, or accidentally discharged to the Salton Sea. In 1963, California regulatory authorities prohibited this practice, and by 1965, surplus brine was injected into several wells (Palmer et al., 1975). Since then, all of the effluent produced at the Salton Sea field is injected.

At the CPGF a large evaporation pond was built west of the wellfield for the disposal of waste geothermal brines. This pond has been periodically enlarged to accommodate the increasing volume of brines; presently the pond has an area of about 16 km^2. Although more in theory than practice, injection is now generally considered by CFE the preferred method of brine disposal at this field (Gutiérrez and Ribo, 1994). Injection began at CPGF in 1989; by 1993, injection rates of 24 percent of production were reached, but rates have declined since (Truesdell et al., 1997). Silica deposition at CPGF is prevented by injecting only brine from the evaporation pond where most silica is precipitated. Recently hot injection at separator pressure has been tried with good results.

Unlike Mexico, where under the Napoleonic code the State owns the minerals and other resources, in California the title of the geothermal resources was clouded by conflicting definitions, mineral legal precedents and tax considerations. The service area (Imperial Valley) was supplied by hydropower and plants fueled by plentiful and low-cost natural gas. Interstate gas pipelines crossed the valley. After the OPEC-induced fuel crises of the 1970s, public policy changed to foster development of renewable energy, including special provisions for geothermal energy (Signorotti and Hunter, 1992). Rights for private industry to exploit geothermal resources became available and development became economically feasible due to the increase of fossil fuel prices and favorable power sales contracts and tax incentives. In 1989, a 230 kV transmission line was installed which allowed geothermal power to be sent north to the system serving the Los Angeles region.

At present, the installed capacities at CPGF and SSGF are 620 and 248 MW, respectively, making them the largest developed liquid-dominated geothermal systems in Mexico and the US. Additional power plants are planned in both fields. Further expansion of either field will mainly depend on economic and demand growth factors, although public policy in favor of renewable energy, e.g. to meet Kyoto global warming goals, may foster development.

SUMMARY·

The Cerro Prieto and Salton Sea geothermal fields are alike in certain aspects and quite different in others. Both have similar geologic frameworks and maximum measured temperatures (350-370°C). They differ slightly in lithology (more continental, especially lacustrine sediments at the SSGF) and ultimate energy capacities (more than 800 MW at CPGF, more than 1000 MW at SSGF).

However, there are large differences in the chemistry of their geothermal fluids and in the amount of evaporites and sulfides in their sedimentary columns, both being higher at SSGF. Dissimilar conceptual models apply to the two fields.

The contrasting fluid chemistries may be explained by the positions of the fields with respect to the crest of the Colorado River delta. South of the crest, in areas that are in good communication with the sea (i.e., the Gulf of California to the south), salts do not accumulate in the deltaic sediments because surface and groundwaters tend to flow toward the Gulf. On the other hand, at the SSGF located in the closed Salton depression north of the delta crest, salts have accumulated because waters can only leave the basin by evaporation.

In both areas concentrated brines have infiltrated and accumulated in deep sediments of the Salton Trough. At SSGF the brines had higher salinities and were of continental origin, while at CPGF they were less concentrated and mainly marine. When the pull-apart basins “appeared” and the two areas were heated by the igneous intrusions, the brines were mobilized forming diapirs which did not reach the ground surface. At CPGF mixing of the ascending brines with less saline groundwaters was significant, while at SSGF and because of the higher density contrast between the brines and the local groundwaters, mixing was minor.

The need to solve the problems of handling the higher salinity (and corrosivity) of the SSGF fluids, as well as differences in US public policy and economic considerations, were the main factors that delayed the development of SSGF compared to that of CPGF in Mexico.

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