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Energy and Lithium Extraction at the Salton Sea (USA) and Cerro Prieto (Mexico) Geothermal Fields

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ABSTRACT

The two largest geothermal fields generating electricity in southern California, USA, and adjacent northern Baja California, Mexico, are the Salton Sea Geothermal Field (SSGF), in California, and the Cerro Prieto Geothermal Field (CPGF), in Baja California. Both fields have similar tectonic environments of pull-apart structures developed at right-stepping, right lateral, strike-slip faults. Their reservoir rocks are both largely deltaic and lacustrine sediments deposited by the Colorado River, with a higher content of lake sediments at the SSGF. The sizes of these two geothermal fields are about equal, and both have downhole temperatures reaching as high as 350-370°C at 2-3 km depths. The salinity of their reservoir fluids is the main difference between them. The CPGF brines have a salinity of ~5% TDS, while the salinity of the SSGF brines is ~28% TDS. This results from the SSGF being near the lowest part of the Salton Trough that forms a closed basin with a surface elevation of ~90 m below sea level. In the past, this depression was repeatedly filled by the Colorado River flowing north, forming large lakes. Each time the river resumed its southerly course to sea level at the Gulf of California, these lakes dried up, leaving behind evaporites, that are the source of the higher salinity of the SSGF brines. Different socioeconomic factors across the international border led to different development of these two geothermal resources. At its maximum, the CPGF had 720 MWe of installed electrical capacity, but now, after 50 years of generation, its capacity has declined to <570 MWe due to falling reservoir pressures. Development was slower at the SSGF, due to both the higher salinity and the difficulty in getting power purchase agreements. The SSGF currently has an installed generating capacity of only 432 MWe, but a minimum of 395 MWe will be added in the near future. However, the salinity of the SSGF brines, which was a disadvantage for developing electrical generation, is now turning out to be an asset. The SSGF brines contain valuable concentrations of metals, including up to 250-300 mg/kg of lithium, now in great demand for lithium-ion batteries. Preliminary estimates of the value of the lithium in the SSGF and adjacent area brines are >US$10 billion, so today the first steps in developing a world class lithium extraction industry and battery manufacturing plant at the SSGF are underway. The brines produced at the CPGF contain up to 20 mg/kg of lithium. At the CPGF disposal of most of the spent brine, after steam separation, is in a large evaporation pond of about 14 km^2 area where more than 970 metric tons of lithium are concentrated each year.

1. INTRODUCTION

The landward extension of the Gulf of California tectonic regime, the Salton Trough of the Mexicali Valley of northern Baja California, Mexico, and the Imperial Valley of southern California, USA, contains numerous geothermal systems hosted in deltaic, alluvial, and lacustrine sediments deposited by the Colorado River. Most of these geothermal systems have no surface expression as hot springs, fumaroles, and other hot manifestations are usually absent. Minor igneous intrusions are common in these systems and the density of rocks that host these geothermal systems has been increased hydrothermal activity, so these "blind" systems were identified by a program of drilling shallow (100 m) temperature gradient holes on positive residual gravity anomalies (Rex *et al.*, 1971; Fonseca *et al.*, 1981).

The two largest and hottest (350-370°C) systems in the Trough are Cerro Prieto Geothermal Field (CPGF), 35 km south of the Mexico-USA international border, and the geologically similar Salton Sea Geothermal Field (SSGF) to the north. These are the two largest, developed, liquid-dominated geothermal fields in North America. They are similar in sizes, temperatures, and geological settings. The first commercial scale geothermal power production from a liquid-dominated geothermal resource in North America took place at the CPGF in 1973, when two 37.5 MWe geothermal single flash plants began operation. In the succeeding decades the installed generating capacity of the CPGF had grown to 720 MWe by 2000, with the drilling of numerous new wells and the implementation of parallel high-pressure and low-pressure dual flash systems. However, now, after 50 years of operation, the installed capacity at the CPGF has declined to 570 MWe and the effective generation in 2021 was equivalent to only 330 MWe (Gutiérrez-Negrín *et al.*, 2023) due to declining reservoir pressures. Development was slower at the SSGF, as the first power plant of only 10 MWe was not commissioned until 1982. At present (2023) the SSGF has a total installed generating capacity of 434 MWe, most of which became operational between 1985 and 2000. The most recent resource assessment of the SSGF's geothermal potential to 3 km depth indicates that this reservoir has very large geothermal reserves, capable of generating 2375 MWe for 30 years (Kaspereit *et al.*, 2016). In contrast to the decline at CPGF, developers at the SSGF report that drilling, and construction are currently underway to add a minimum of 395 MWe of new electrical generation now and up to 1100 MWe more in future.

The purpose of this present report is to compare the geology and geochemistry of the CPGF and the SSGF, to discuss the factors that have controlled their development as sources of electrical power, and to contrast their likely commercial development in the future, especially in the light of the recent burgeoning interest in extracting valuable metals, such as lithium, from their geothermal brines. Recently the price of battery grade lithium carbonate increased by a factor of five now selling for ~US $28,500 a metric ton (Ohnsman, 2020).

2. THE SALTON TROUGH

The Salton Trough is the northernmost part of the Gulf of California tectonic system that was initiated during the early Pliocene, 4 to 5 million years ago (Herzig and Jacob, 1994). At that time major crustal extension began splitting Baja California from mainland Mexico and the waters of the Gulf extended northwards to about the area now occupied by the Salton Sea. In the mid-to-late Pliocene (2 to 3 million years ago) the Colorado River began depositing its deltaic sediments in the area around Cerro Prieto, eventually leading to the closure of the connection between the waters of Gulf of California and the Imperial Valley. This closure was completed by the late Pliocene and since then the northern basin has received only continental sediments. The rocks that now partially fill the Trough consist of poorly indurated sands, silts, and mudstones, characterized by rapid lateral and vertical variations in lithofacies (Diblee, 1954; Van de Kamp, 1973).

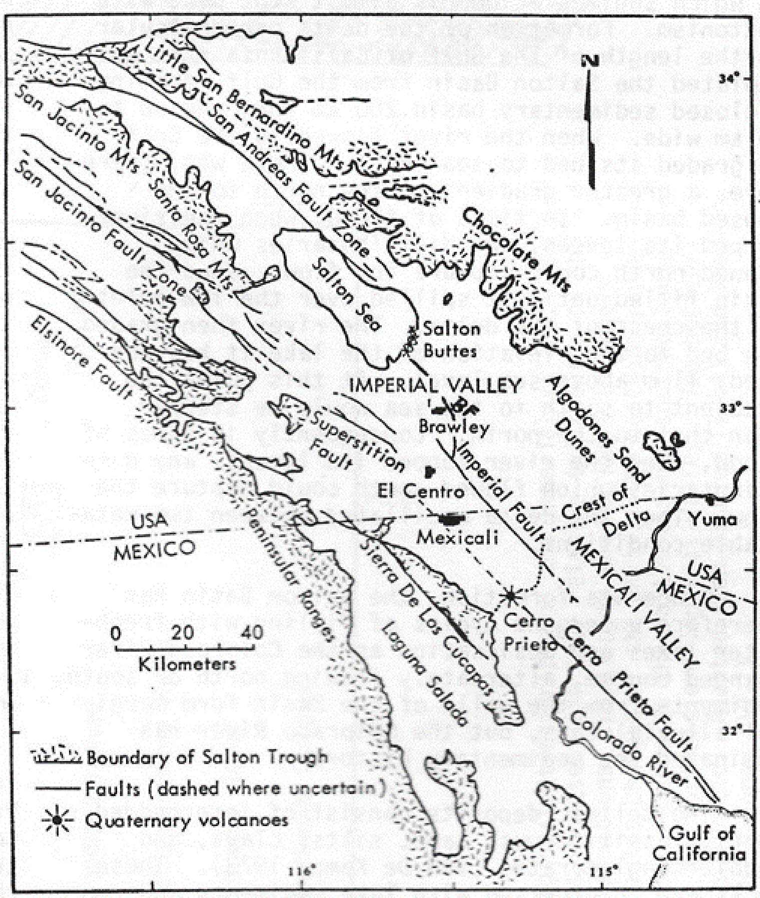

Fig. 1. Regional geological map of the Salton Trough showing the basin margins and principal faults, location the SSGF at the Salton Buttes volcanoes, the CPGF and the Cerro Prieto volcano, and the crest of the delta of the Colorado River in the Trough. BF is the Brawley Fault.

The Trough is a roughly triangular depression ~300 km long from its northern apex to the Gulf of California to the south, and about 100 km wide at the international border (Fig. 1). This complex rift valley is bordered by mountains and hills consisting of Mesozoic and older granitic and metamorphic crystalline rocks, and Tertiary volcanics. The Peninsular Ranges form its boundary to the south-west, the Little San Bernardino and Chocolate Mountains form its boundary to the north-east, and the tidal flats of the Gulf of California form its southern boundary. The Colorado River enters the Trough from the east at Yuma at an elevation of ~43 masl (meters above sea level) forming a delta that partially filled the basin as it developed along the boundary between the North American and Pacific tectonic plates. Within the Salton Trough, the delta has a crest (at 12 masl at the CPGF) that is a low divide slopping south towards the Gulf of California and north towards a closed basin with an elevation of ~90 m *below* sea level (mbsl), at its lowest point (Figure 1). This northern basin lacking any hydrological outlet, and formerly known as the Salton Sink, is now occupied by a large terminal lake, the Salton Sea, with an area of 930 km^2 that currently has a surface elevation of ~85 mbsl. The modern Salton Sea is maintained by the runoff from irrigation in both the Mexicali and Imperial Valleys. Today, because of reduced inflow, the area of the lake is shrinking, creating widespread ecological problems.

Sheltered in the lee of the coastal mountains that trap the rainstorms sweeping in from the Pacific Ocean, the Salton Trough's low rainfall, elevated temperatures, and drying winds produce one of the world's driest and hottest climates. In this low Sonoran-type desert basin, the mean annual precipitation is between 5 and 10 cm and the average ambient temperature for July exceeds 33°C, with peak temperatures reaching 51°C. Until the initiation of colossal irrigation schemes in the 1920's, the Salton Trough was a desolate and sparsely populated region. Now irrigation has transformed this landscape (see Figure 2).

The Trough is transected by a system of major strike slip faults such as the San Andreas, Brawley, Imperial, and Cerro Prieto faults, which are a continuation of the tectonic regime developed along the oblique-slip transform boundary between the North American and Pacific tectonic plates in the Gulf of California (Elders *et al.*, 1972; Lachenbruch *et al.*, 1985). The major geothermal systems of the Salton Trough are thus situated in a tectonic regime of crustal thinning, in pull apart basins formed by the *en-echelon*, right stepping, right lateral, strike-slip faults, or 'leaky' transform faults (Elders and Biehler, 1975).

3. GEOTHERMAL SYSTEMS OF THE SALTON TROUGH

The SSGF, at the south end of the Salton Sea, and the CPGF, about 35 km south of Mexicali, are only two of several developed geothermal systems in the Salton Trough. Figure 2 shows the locations and installed capacities of all the geothermal power plants currently operating in the Imperial Valley.

South of the border, geothermal systems have been identified at Cerro Prieto, Tulecheck, Mesa de Andrade, Mesa San Luis, and Panga de Abajo (Fonseca *et al.*, 1981). However, the only operating geothermal power plants in the Mexicali Valley are at the CPGF (Fonseca *et al.*, 1981). The other geothermal systems discovered in the Mexican part of the Salton Trough are apparently not suitable for commercial power production.

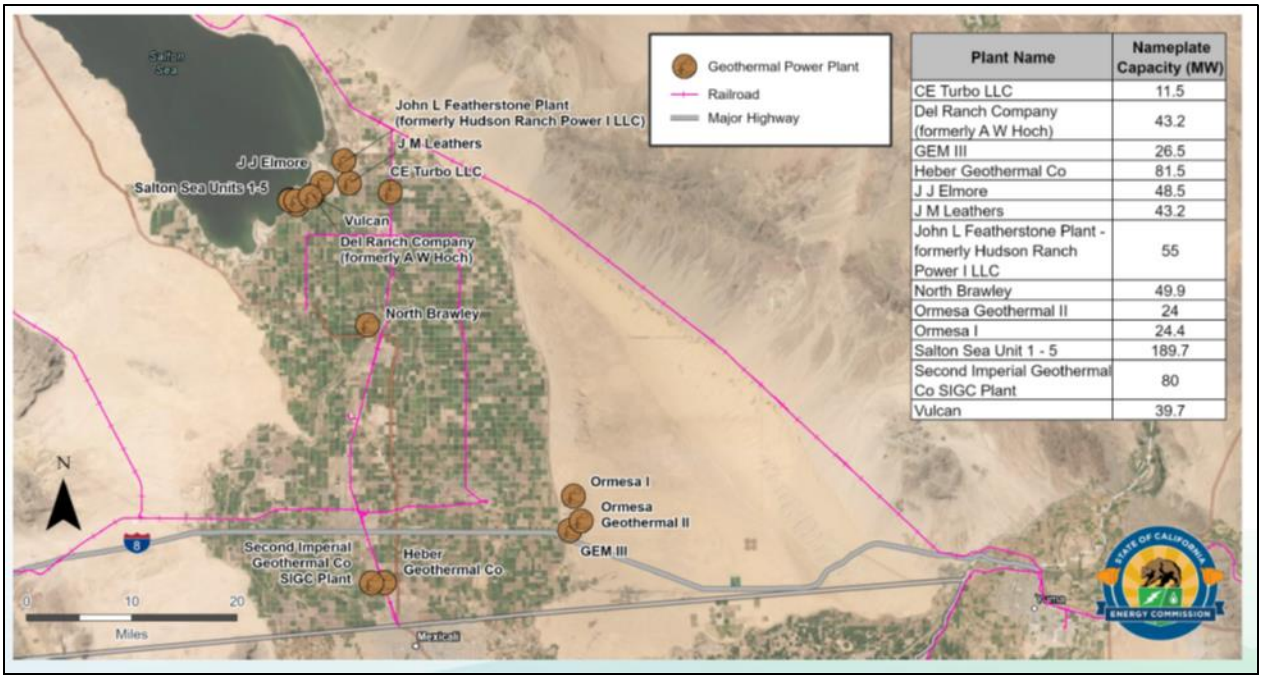

Fig. 2. Satellite image of the USA part of the Salton Trough, with the locations of the geothermal power plants operating in March 2022 and a list of their nameplate capacities (California Energy Commission, 2022).

The total installed name plate capacity of all the geothermal power plants in the Salton Trough was approximately 1439 MWe, including 720 MWe installed at the CPGF and 433.4 MWe in eight power plants at the SSGF. Development was more rapid and larger at the CPGF than at the SSGF because of the greater demand for electricity in the Mexicali Valley. Mexicali and Tijuana together have around three million inhabitants with numerous industrial plants in the border zone needing electrical power. The Baja California electric net (SIBC, Interconnected System of Baja California) is an isolated system, not connected to the Mexican national grid and so requires its own electrical generation. Before the CPGF began production, northern Baja California relied entirely on generation from oil-fired plants at Rosarito, on the coast of Northern Baja California, which were supplied by tankers bringing oil from the Gulf of Mexico. At its peak, in 1989, geothermal energy produced in the CPGF was able to supply 79.8% of the demand in the SIBC, and even in 2021 CPGF provided 20% of the total demand in that isolated system (Gutiérrez-Negrín *et al.*, 2023).

The factors that slowed development of geothermal power at the SSGF were partly technical and partly economic. Scaling and corrosion due to very high chloride concentration and the deleterious effects of amorphous silica precipitation hindered the initial attempts to process the brine to produce steam for power generation. Firstly, the highly concentrated SSGF brines are very corrosive to well casings, requiring using hydrogen inhibitors and sacrificial liners to avoid the cost of expensive corrosion resistant alloys. Secondly, after removing flashed steam, the brine becomes supersaturated with silica and iron compounds that can plug the injection wells that are necessary for disposal of the spent brine and for maintaining fluid pressures in the reservoir. This has been successfully overcome by use of reactor clarifiers in which silica and iron are precipitated and removed for surface disposal before the brine passes to the injection wells (Hoffman, 1975; Featherstone *et al.*, 1979).

The capital and operational costs are therefore higher at the SSGF than at the CPGF, but this is partially offset by the efficiency of its turbines due the higher enthalpy of the steam produced there. Another issue was the lower market for electricity in the Imperial Valley, but more recently this has been alleviated by improvements in the interconnections to California's power grid. However, perhaps the key factor was that development of geothermal power in California has had to compete with the historically low prices and ready availability of natural gas, solar, and wind power in the state.

4. OPERATIONAL DIFFERENCES BETWEEN THE CPGF AND THE SSGF

The development of the CPGF and the SSGF had two major differences: (1) disposal of the spent brine left after separating the flashed steam, and (2) the number of production and disposal wells drilled. In California environmental laws require disposal of spent brine by injection in deep wells in order not to contaminate shallow groundwater aquifers. At Cerro Prieto a less expensive disposal method was used by sending most of the spent brine to a large solar evaporation pond of approximately 14 km^2 in surface area.

The difference in the number of production and disposal wells between the two fields is striking. At the SSGF the total number of exploration, production and disposal wells is about 65 to generate 433 MWe, whereas at the CPGF there were 157 production and injection wells operating in 2021 for the production of 570 MWe. Evidently, the drilling budget at the CPGF is much larger than that at the SSGF. It would appear that the main response to falling reservoir pressures at the CPGF has been to drill more wells.

In terms of their respective geothermal fluids, the main difference between the two systems is their total salinity (TDS). The CPGF fluids have salinities in the range of 3-5% TDS, whereas the SSGF brines are unique among the world's developed geothermal resources in having extremely high salinity, containing up to 30% TDS before flashing. An earlier report by Lippmann *et al.* (1999) comparing the chemistry of the CPGF and the SSGF brines concerned that point.

Table 1 compares the chemistry of fluids from representative geothermal systems in the Salton Trough. The brines at Cerro Prieto, East Mesa, and Heber have somewhat similar chemistry, whereas those at Salton Sea and Imperial are 16 times more concentrated.

However, Mg and Ca concentrations at the SSGF are 100 times more concentrated than those at the CPGF. SiO_2 concentrations at the higher temperature Salton Sea, Imperial, and Cerro Prieto systems are similar, and twice as high as those in the moderate temperature systems of East Mesa and Heber. These similarities and differences result from: (1) the nature of the groundwater at each site that was heated by igneous intrusions, which in turn depends on the relative position of the system on the Colorado River Delta, and on (2) hydrothermal reactions between this groundwater and the reservoir rocks.

Table 1. Analyses of typical geothermal fluids in the Salton Trough. Data in mg/kg, calculated to reservoir conditions (McKibben and Hardie, 1997).

	Salton Sea	*Imperial*	*Cerro Prieto*	*East Mesa*	*Heber*
Well:	***S2–14***	***L2–28***	***M–5***	***6–1P***	***5***
Temperature (℃):	***330***	***275***	***300***	***~ 190***	***195***
Depth (m):	***2500–3220***	***3290–4270***	***~ 1200***	***~ 2164***	***~ 1800***
Na	54,800	50,466	5,004	6,362	4,019
Ca	28,500	18,140	284	759	750
K	17,700	9,555	1,203	1,124	333
Fe	1,710	3,219	<1	NA	NA
Mn	1,500	985	1	NA	NA
SiO_2	>588	465	569	257	237
Zn	507	1,155	NA	NA	NA
Sr	421	1,500	NA	NA	41
B	271	217	11	NA	4
Ba	~ 210	2,031	NA	NA	4
Li	209	252	13	NA	7
Mg	49	299	<1	9	2
Pb	102	>262	NA	NA	NA
Cu	7	>1	NA	NA	NA
Cd	2	4	NA	NA	NA
NH_4	330	NA	NA	NA	6
Cl	157,500	131,000	9,370	11,668	7,758
Br	111	NA	31	NA	NA
CO_2	1,580	30,000	2,400	NA	186
HCO_3	NA	NA	NA	221	NA
H_2S	10	>47	180	NA	1
SO_4	53	NA	4	51	66
TDS	**26.5%**	**25.0%**	**1.6%**	**2.2%**	**1.3%**

Because the reservoir rocks in the Salton Trough contain very little Cl and Br, the Cl/Br ratios of these various brines are useful indicators of their origins. Cl/Br ratios seem not to be affected by hydrothermal reactions even at 300°C. The Cl/Br ratios of the CPGF brines (~300) are close to that of seawater suggesting a marine origin for its dissolved salts. On the other hand, the very high Cl/Br ratios of the SSGF and Imperial geothermal brines indicates that the salts in these brines reflect a continental rather than a marine origin, as they originated by the dissolution of non-marine evaporites formed from waters from the Colorado River and its ancestors. The ~100 m difference in surface elevation of CPGF (12 masl) and the SSGF (85 mbsl) had an enormous effect on their fluid chemistry.

Before the construction of multiple upstream dams, the course of the Colorado River in the Salton Trough was unstable. Most of the time it flowed south to the Gulf but at times it flowed north to Salton Sink. From the apex of the delta in the Mexicali Valley at ~12 masl, the delta slopes southwards towards the Gulf at ~0.35 m/km, but it slopes northwards towards the Salton Sink at ~0.8 m/km. When flowing to the Gulf, the gradient of the river was controlled by sea level. During the spring floods, at times the river could overflow its levees and, as distributaries flowing north had steeper gradient, they would capture the total flow of the river directing it towards the base level for northward flow of 90 m below sea level, forming lakes, which were ancestral to the modern Salton Sea.

When these large fresh-water lakes filled the basin, they would have a surface elevation 12 masl. The river would then grade its bed to 12 masl, an unstable situation as, in that condition, the gradient to the south would be steeper than that to the north. Flooding over the levees of this northward flowing river would cause the river to resume its southerly course. This flip-flop must have occurred multiple times. The most recent iteration of this process created a lake which formed prominent shorelines on both sides of the Imperial Valley that archaeologists have named Lake Cahuilla (Waters, 1983). Lake Cahuilla and its predecessors would dry up whenever the river resumed its southerly course. The result of this process in the deeper parts of the basin is the more abundant lacustrine sediments in lithologic column (Herzig *et al.*, 1994) and the high salinity of brines produced from wells in the deeper part of the basin.

The chemistry of these brines also reflects the effects of water-rock reactions especially in the high-temperature geothermal systems, such as the CPGF, SSGF and Imperial geothermal fields. Figure 3 shows the temperatures at which hydrothermal minerals are stable due to water-rock reactions in the CPGF (Elders *et al.*, 1984). In spite of the great difference in TDS of its geothermal fluids, hydrothermal alteration at the SSGF is almost identical to that at the CPGF. One difference is that at the SSGF anhydrite is present at temperatures ~100°C, and other is that garnet makes an appearance above 350°C. At the CPGF the content of Ca in the brines is reduced relative to seawater (which contains 400 mg/kg) by the precipitation of dolomite, calcite, and epidote. Similarly, Mg concentrations are reduced relative to seawater (1350 mg/kg) by the formation of chlorite, epidote, and pyroxenes.

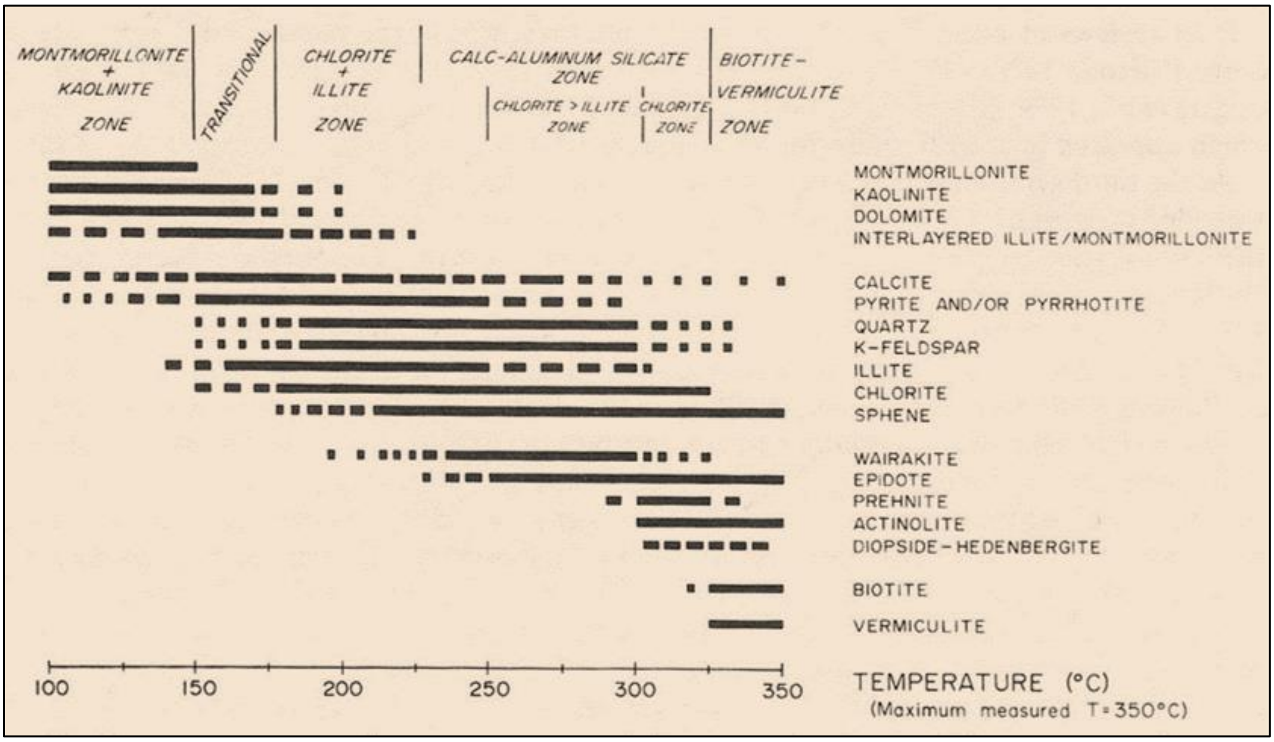

Fig. 3. Temperature ranges of hydrothermal alteration minerals in the Cerro Prieto Geothermal field (Elders *et al.*, 1984).

5. DIRECT METAL EXTRACTION

The hot hypersaline brines of the SSGF reservoir typically contain about 1500 mg/kg of Mn, 500 mg/kg of Zn, and 200 mg/kg of Li. The potential to exploit such high concentrations of metals in geothermal brine was a focus of earlier investigations at the SSGF (Werner, 1970; Hornburg, 1975). However, the deleterious effects of amorphous silica precipitation and scaling, together with corrosion due to high chloride concentration, hindered initial attempts to use the hot brine to make steam for power generation. Today at the SSGF, along with proposed increases in power production, there is great interest in extracting valuable metals, especially lithium, from the SSGF brines (Warren, 2021). The direct extraction of lithium from geothermal brines is expected to have much lower environmental impacts compared with traditional methods of sourcing lithium, which use hard-rock mining or solar evaporation ponds, and also to be economically competitive with them (McKibben *et al.*, 2021; McKibben, 2022).

In 2022 the high salinity of the SSGF brines that was originally a barrier to economic development is turning from a liability into an asset. Previously, from 2000-2004, CalEnergy, the principal operator of the field, extracted commercial quantities of high-grade zinc from the geothermal brine, using solid-liquid ion exchange. This plant was decommissioned due to a combination of technical difficulties of process control and declining market conditions (Harrison, 2014). Today the focus is on lithium. McKibben *et al.*

(2021) conservatively estimated that the potential additional revenues from lithium sales far exceeds the revenues from power sales. They calculated that the currently exploited volume of the geothermal reservoir, to a depth of only 2 km at the SSGF contains 11 km^3 of hypersaline brine. This contains at least 15 million tonnes (metric tons) of manganese, 5 million tonnes of zinc, and 2 million tonnes of lithium. Any expansion of the dimensions of the brine reservoir would significantly expand these resource estimates. To appreciate the magnitude and significance of these conservative estimates, it is informative to compare projected estimates of likely annual production from the SSGF with the annual consumption in the USA (Table 2). The lithium pass-through in the existing power plants at the SSGF geothermal plants is estimated to exceed 24,000 tonnes/year of LCE (lithium carbonate equivalent), based on 2019 geothermal plant operations (Warren, 2021). At current prices the value of annual flux of lithium passing through the existing geothermal power plants at the SSGF is of the order of a billion US dollars.

Table 2. Potential metal production in metric kilotons per year (ktpa), from SSGF brines based on the electrical capacity at only the CalEnergy power plants (Besseling, 2018; McKibben et al., 2021).

Metal	Current Capacity (350 MW)	Projected Capacity (700 MW)	Annual U.S. Consumption
Lithium	17	40	2
Zinc	32	100	950
Manganese	98	310	740

The current market for lithium for use in lithium-ion batteries for electric vehicles and for batteries that store electricity from intermittent sources, such as wind or solar generation, is growing explosively. In mid-April 2021 lithium carbonate spot market prices in China averaged US$15,000/tonne and lithium hydroxide monohydrate sold at US$21,000/tonne (Fastmarkets, 2021). In April 2022 the prices quoted for battery grade lithium carbonate was US$78,350/tonne and lithium hydroxide used in batteries with high nickel cathodes sold for up to US$10,000/tonne more (Benchmark Mineral Intelligence, 2022).

If only 14% of new car sales were electric (EV's), which is possible globally in 2025, annual world demand for lithium could be ~1 million tonnes. CalEnergy and Energy Source Minerals, the two operators of existing geothermal power plants at the SSGF, are building pilot plants that will begin producing lithium carbonate or hydroxide before the end of 2024. Controlled Thermal Resources, a new developer at the SSGF, is also proposing developing power production and lithium extraction with a similar time frame. At the SSGF we are witnessing the start of a world class direct lithium extraction industry (DLE), that will be in the future the basis for manufacturing lithium-ion batteries in the Imperial Valley. On April 2nd, 2022, at a meeting of Imperial Valley Economic Development Corporation, Statevolt, a newly formed company, announced plans to build a 54 GWh lithium-ion battery factory at a cost of US$4 billion in the Imperial Valley. If this plan is implemented, this factory would have 2500 employees and manufacture 50,000 batteries in 2025 and 650,000 in 2028.

In contrast, the data of Table 1 show that the concentration of lithium in the brines produced by wells at the CPGF is about 5% of that at the SSGF. None-the-less there is interest in exploring the potential for mineral extraction at the CPGF, in spite of their lower concentrations. This is credible because at the CPGF metal concentrations have been greatly increased in the spent brines sent to the evaporation pond which was built in 1984 by Fertimex, to concentrate potassium and magnesium chloride for fertilizers. The pond was originally designed to receive and treat a maximum flow of 1 m^3/s of brine, i.e., 3600 tonnes/hour. This fertilizer project was eventually abandoned, and the present use of the pond is only to dispose ~60% of the separated brine. Injection of the remaining 40% of the brine produced after steam separation began in 1984. According to the data of CFE (the Federal Electricity Commission of Mexico that operates the CPGF), the brine currently being sent to the evaporation pond contains an average of 19.1 mg/kg of lithium and it currently flows to the evaporation lagoon at a rate of up to 5800 tonnes/hr. Thus, the lithium dissolved in the brine is being discharged to the evaporation pond at a rate of about 110 kg/hour ($5.8 \times 10^3 \times 19.1$ g/hr) or 970 tonnes/year, not accounting for any lithium that co-precipitates with silica on its journey from the wellhead steam separators to the evaporation pond. Thus, between 1984 and 2022 almost 37,000 tonnes of lithium should have accumulated in the evaporation pond. However, the CFE periodically dredges the pond to prevent it overflowing, and so the actual amount of lithium remaining in the pond is uncertain.

The operations at the CPGF have created an artificial saline lake and salt flat. Approximately 48% of the commercial production of lithium worldwide comes from natural saline ponds (salars) on the Altiplano of the Andes of Chile, Bolivia, and Argentina (Warren, 2021). There, lithium chloride and other salts are concentrated via passive solar evaporation for a year or longer. After the water has evaporated to sufficiently concentrate lithium to approximately 6000 mg/kg, non-lithium constituents are separated by precipitation with addition of chemical reagents, primarily slaked lime ($Ca(OH)_2$). The lithium-enriched solution is then transferred to a processing plant where remaining unwanted constituents are removed from the solution by additional non-evaporative techniques that are typically proprietary (Warren, 2021). The difference between the evaporation lagoon at the CPGF and a natural salar is that the Cerro Prieto spent brines are saturated in silica, making extraction of lithium more difficult. None-the-less, a study of concentrations and abundance of lithium, and possible direct lithium extraction methods from the CPGF evaporation pond and the materials dredged from it seems warranted.

6. SUMMARY AND CONCLUSIONS

The SSGF and the CPGF have the largest installed generating capacities of any water-dominated, geothermal fields in North America. They are geologically similar as they formed in similar tectonic environments of oblique-slip rifting and igneous intrusion on the delta of the Colorado River in the Salton Trough. However, the geochemistry of their geothermal fluids is strikingly different as the SSGF geothermal brine, before flashing to remove steam for its turbines, has a TDS percentage sixteen times more concentrated than that of the CPGF brines. This difference is due to the relative elevation of these two geothermal fields on the delta. The Colorado River delta has prograded across the Salton Trough, isolating a hydrologically closed basin to the north from an earlier connection to the waters of the Gulf of California to the south. The CPGF is situated on the apex of the Colorado Delta at about 12 m above sea level, at the divide between the waters of the Gulf of California to the south and the closed basin to the north that has a surface elevation of about 90 m below sea level at its lowest point. The very high salinity of the SSGF brines results from the incorporation of non-marine evaporites that formed by the drying up of freshwater lakes that formerly filled this closed basin, as the ancestral Colorado river switched from flowing north to the basin, to flowing south to the Gulf of California.

This difference in salinity was one of the factors that led to electric power production being installed at the CPGF much earlier than at the SSGF. Two other major differences in their development as sources of electrical generation are: (1) the much higher number of wells drilled for production and disposal at the CPGF compared to the SSGF), and (2) the disposal of the spent brine left after separating the flashed steam. At the SSGF all spent brine and condensed steam is injected into disposal wells, thus helping to maintain fluid pressures in the reservoir. At the CPGF 60% of the spent brine is sent to a large evaporation pond, with the rest going to injection wells.

We are witnessing the birth of a new, rapidly growing industry in the Salton Trough. Today the focus of new developments of the geothermal resources of this area is shifting from electrical power production to direct recovery of trace metals needed for manufacturing electrical storage batteries, especially lithium-ion batteries. Lithium concentrations in the range of 250-300 mg/kg in brines from wells near the southern end of the Salton Sea have led the three developers of the field to begin building pilot plants to extract lithium directly from the SSGF geothermal brines. Although the concentration of lithium in brines produced from wells at the CPGF is much lower than at the SSGF, lithium and other trace metals have been concentrated at the surface at Cerro Prieto. During almost 38 years of operation of the evaporation pond, approximately 37,000 tonnes of lithium have been extracted from the geothermal reservoir and now remain at the surface in the pond and in the material dredged from it. This would be worth more than US $100 million if that lithium could be recovered. However, the silica that accompanies the precipitation of lithium salts in the pond could be an additional problem for lithium recovery. There is also the problem in this arid region of finding a source of freshwater to leach out lithium salts. Never-the-less, given the large potential economic yields, further investigations seem warranted.

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