A new geothermal resource in Los Cabos, Baja California Sur, Mexico

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A NEW GEOTHERMAL RESOURCE IN LOS CABOS, BAJA CALIFORNIA SUR, MEXICO

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SUMMARY – The geothermal potential in Baja California has been well known as exemplified by developments at Cerro Prieto and Las Tres Vírgenes. However, conventional exploration studies have overlooked an area in Los Cabos that may well comprise an important geothermal resource. Recent investigations of coastal hydrothermal systems in Baja California Peninsula provide evidence of the occurrence of thermal anomalies in the area of Los Cabos, Baja California Sur.

Los Cabos is an important tourist area with a growing water demand, and the possibility of using geothermal water in desalination processes has stimulated funding to study coastal wells that discharge hot water. Chemical geothermometers yield equilibrium temperatures close to 200°C, and oxygen and hydrogen isotopic values indicate an important oxygen shift in the thermal water, mixing with seawater, and a chemical affinity with submarine hydrothermal systems.

1. INTRODUCTION

Although there are several works reporting geothermal springs or wells in the Peninsula of California (Vidal, 1978; Quijano, 1985: Casarrubias and Leal, 1993; Casarrubias and Romero, 1997; Portugal et. al., 2000; Barragan et. al., 2001; Prol-Ledesma, 2004), this is the first time that geothermal activity has been reported in Los Cabos area (Cabo San Lucas and San Jose del Cabo), the southern most area in Baja California Sur, Mexico (Fig. 1).

Baja California Peninsula, and especially Los Cabos area (Baja California Sur State-BCS), is one of the main tourist destinations in Mexico; however, the California Peninsula is relatively disconnected from the rest of Mexico and the supply of fuel to this region is quite expensive. Tourist development has lead to a rise in the population and consequently a great increase in energy and water demand. In the process of drilling some wells to supply the desalination plant in Cabo San Lucas, hot water, probably related with a hydrothermal system, was found. Therefore, geothermal energy has been considered as a solution for the energy and fresh water problems; in addition to providing geothermal energy, the hot water can be used also in desalination processes. Moreover, the hot water can be used in Spa's facilities that would increase the tourist offerings in the region.

Three geothermal wells have been drilled in this area and here we present the results of geochemical and isotopic analyses. These analyses were used to define the origin and processes that might have occurred to these waters and to estimate the reservoir temperature (Henley et. al., 1884; Giggenbach, 1988; Nicholson, 1993).

Five samples were collected from wells in Los Cabos area and analyzed for their chemistry and isotopic composition. Three of them are geothermal water (two from Cabo San Lucas – LC-4 and LC-5, and one from San Jose del Cabo – LC-6), two more are from cold wells of a desalination plant in Cabo San Lucas (LC-1 and LC-2) and one is a seawater sample (LC-7). All the wells are located near the coast (Figure 1). The objective of this work is to define the type and origin of the geothermal fluids and estimate the reservoir temperatures.

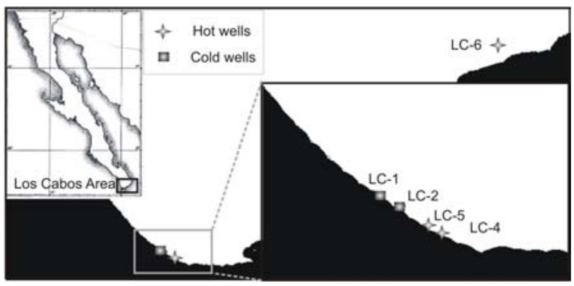

Fig. 1. Location of the sampled wells.

2. GEOLOGY

Los Cabos is the southernmost part of Baja California Sur. In this area, outcrops are constituted by intrusive rocks of the "Complejo Plutónico de La Paz" that forms Sierra de la Trinchera in Baja California Sur; it was described by Ortega et. al. (1992) as Mesozoic plutonic mafic rocks from an arc root of gabbroic composition.

In a more recent work, Schaaf et al. (2000) report a more detailed study of this complex, that they refer to as Los Cabos Block, where they classified it as a tectonic unit with undeformed intrusives with granitic to tonalitic composition, which are found mainly in the south-central part of the peninsula, including the area around Cabo San Lucas" (Schaaf et. al., 2000). These authors suggest a magmatic relation between this plutonic complex and the Puerto Vallarta Batholith in Jalisco. On the basis of paleomagnetic data, they suggest that Los Cabos Block could have had an independent paleogeographical evolution different to the rest of the Baja California peninsula. According to their results, La Paz fault is probably an accretional structure. Therefore, Puerto Vallarta Batholith and Los Cabos Block moved away from each other due to the extensional movements that originated the Gulf of California during Miocene. Because of this movement, the Peninsula of Baja California was separated from the North American Plate and accreted on to the Pacific Plate during the Miocene.

The regional tectonics in Baja California are strongly related with the geodynamic development of the Gulf of California and extension with a lateral component. The result of this geodynamical context is the formation of a young oceanic basin dissected by transform faults. With this setting, a high geothermal gradient is expected and, as a result, there are many hot sprigs and geothermal wells reported in the peninsula. Also, the Baja California Peninsula is one of the major producers of geothermal energy with two geothermal plants actually producing electricity: Cerro Prieto and Las Tres Vírgenes.

Due to this extension between the plates, normal listric faulting systems trending NNW-SSE have developed along the coasts of Peninsula of California, and the evolution of some of them have produced bays like Concepción Bay or La Paz Bay, and islands like Angel de la Guarda. The hydrothermal manifestations in the region coincide with these fault systems.

According to Barragán et al. (2001) the formation of thermal manifestations along the Baja California coast could be related to the heating up and convection of sea water along extensional tectonic structures, as observed in the submarine hydrothermal vents in the Gulf of California and along the East Pacific Rise. A fault has been found between cold wells (LC-1, LC-2) and hot wells (LC-4, LC-5) that could be a hydrologic barrier controlling this hydrothermal system. Another important feature is the desert climate, because of its influence in hydrogeology. Los Cabos has a very hot dry climate. Annual mean temperature is 22-23 ºC and annual mean rainfall is 50-400 mm (Bustamante-García, J. 1999). The scarce rainfall results in creeks that appear after the rain and disappear afterwards.

The study area is located in Los Cabos Block; therefore, the lithology is almost totally composed of granitic rocks, and the permeability is constrained to fractured zones.

3. METHODOLOGY: SAMPLING AND CHEMICAL ANALYSES

Well water samples were collected in April 2006 and stored in Nalgene bottles. One of the bottles was acidified with HNO_3 for determination of major cations, trace elements and rare earth elements. The others bottles were kept unacidified for major anions and isotopic analysis. Temperature, pH, salinity, TDS (Total Dissolved Solids) and electrical conductivity were measured in the field, using a Portable Hach Multiparameter SenION156. Major chemical constituents were analyzed few hours after the sampling. Volumetric method was used for bicarbonate and chloride. Bicarbonate was determined using methyl orange; chloride analysis was made with silver nitrate and potassium chromate as an indicator. Sulphates were analyzed by turbidimetric method using barium chloride (BaCl2) (estimated detection limit, EDL= 7 mg/L); Sulphide was determined using methylene blue method (EDL= 0.01 mg/L). The acidified samples were analyzed for major cations and trace elements in Actlabs Laboratory (Ontario, Canada) by Inductively Coupled Plasma Mass Spectrometry (ICP/MS). Isotopic analyses ($\delta^{18}O$, δD) were determined in the LUGIS Laboratory at the Geological Institute (UNAM) with Mass Spectrometry (see Prol-Ledesma et al., 2004, for a detailed description of the method).

4. WATER CHEMISTRY

Five water samples were collected in Los Cabos: two are from the cold wells (LC-1, LC-2) and three from hot wells (LC-4, LC-5, LC-6). In the analysis of the data, a seawater sample from Bahía Concepción was included (LC-7). Major chemical constituents and physico-chemical parameters are listed in Table 1. The water classification is shown in a Stiff diagram (Fig. 2), all water samples are Na-Cl type.

Trace element concentrations define an enrichment of the thermal water in Hg, Ba, Mn, I, B, Li, As and Cs with respect to seawater, and with respect to the cold wells, except for As, which is also high in the samples from the cold wells.

Rare earth elements are enriched with respect to seawater, in a similar fashion to that observed in other shallow submarine hydrothermal vents Prol-Ledesma et al., 2004).

The plot of $\delta^{18}O$ vs Cl (Fig. 3) shows a linear mixing trend between groundwater and seawater.

Table 1 Chemical analyses of water from Los Cabos wells compared with a seawater sample (LC- 7) as reference

Sample	T °C	pH	Cond mS/cm	TDS mg/L	Na mg/L	Mg mg/L	K mg/L	Ca mg/L	Cl mg/L	HCO_3 mg/L	SO_4 mg/L	Si mg/L
LC-1	25	6.9	1.7	848	290	47.1	14.1	27.0	1279	371.9	105	4.3
LC-2	22	6.4	3.53	1815	722	59.0	35.0	32.0	1826	278.9	200	12.6
LC-4	42	5.6	28.2	16530	5070	75.0	283.0	1210.0	9132	93.0	625	173.9
LC-5	72	5.7	49.6	31000	9820	69.6	631.0	2430.0	15708	93.0	650	240.2
LC-6	36	7.3	6.75	3570	1090	83.7	33.0	190.0	2557	325.4	500	25.9
LC-7*	25	7.8	N.D.	N.D.	11176	1399.9	486.7	392.0	18744	97.6	2554	0.0

All concentrations are in mg/L; Cond. (µS/cm); T (ºC) measured temperatures at surface; TDS (mg/L). N.D., not determined. (*- from Prol-Ledesma et al., 2004)

Isotopic compositions of water samples are presented in Table 2. The water samples LC-1 and LC-2 represent the lowest values, and sample LC-5 the highest value in $\delta^{18}O$ VSMOW (-0.4 ‰) and δD VSMOW (-10.6‰), very close to the seawater value with an oxygen shift.

Table 2. Isotopic composition ($\delta^{18}O$, δD) in ‰ for the water samples

Samples	$\delta^{18}O_{VSMOW}$	δD_{VSMOW}
LC-1	-9.1	-65.9
LC-2	-9.2	-65.9
LC-4	-5.8	-37.2
LC-5	-0.7	-12.8
LC-6	-8.6	-59.8
LC-7*	-0.3	0.3

5. DISCUSSION

The highest measured temperature (72°C) was observed in well LC-5, which is the well with the highest TDS and the lowest pH. The concentrations indicate the presence of mixing with seawater; however, the scarcity of data do not allow calculation of the thermal end-member.

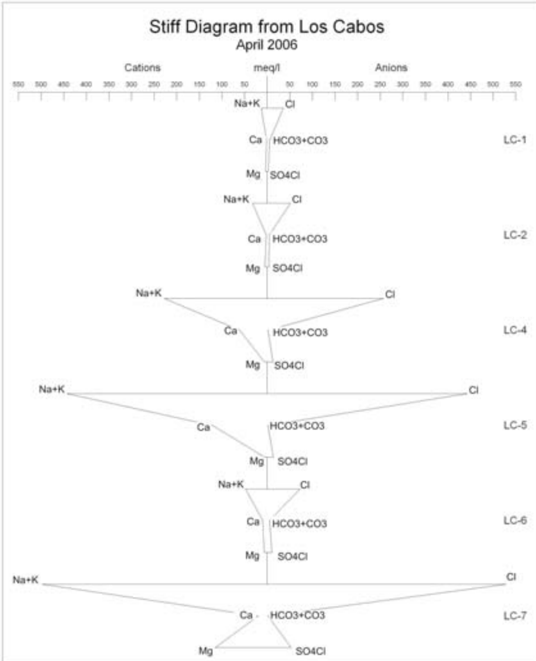

Fig. 2. Stiff diagram for the analysed samples.

Cl/B ratio was calculated for all samples; however, only samples LC-4 and LC-5 present a similar Cl/B ratio. These wells produce thermal water with temperatures of 42.5ºC and 72.1ºC, respectively, probably from the same source.

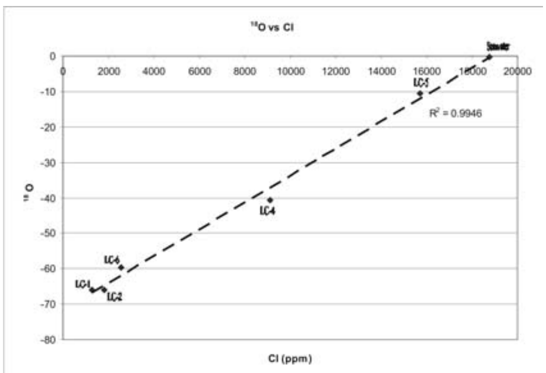

Fig. 3. Plot of $\delta^{18}O$ vs Cl for the studied samples

The silica geothermometer was applied to samples LC-4, LC-5 and LC-6, and it yields temperatures of 171°C, 193°C and 73°C. These temperatures can be considered as minimum because the samples show the occurrence of mixing with seawater. Cation geothermometers can be applied only when full or partial equilibrium is attained between rock and fluid (Giggenbach, 1988); therefore, the water chemistry data were analysed to verify the presence of equilibrium. After plotting Na-10*K-√Mg, it was observed that only the hot water samples from wells LC-4 and LC-5 were in partial equilibrium and the rest of the samples are immature waters. Na/K geothermometers were applied to samples LC-4 and LC-5, and temperatures of 190 °C and 199°C were obtained. These temperatures are similar to those obtained with the silica geothermometer, which support the hypothesis that the reservoir temperature may be close or possibly higher than 200°C. The high concentrations of Mg in the water samples prevented the application of other chemical geothermometers as Na-K-Ca and K-Mg

Normalized REE concentrations are plotted in figure 4, data from Bahía Concepción shallow vents (Prol-Ledesma et al., 2004) and from MAR and Valles Caldera (Michard, 1989) were included as reference. REE concentrations exhibit a negative anomaly in Eu and Ce in samples LC-4 and LC-5 (Fig. 4). An anomalous behaviour of Eu and Ce is common in geothermal waters (Michard, 1989). REE concentrations are higher in thermal water when compared with non-thermal waters. An enrichment of L-REE vs. H-REE is observed in the studied samples, similar to that observed in seawater and opposite to the behaviour of continental geothermal waters (Fig. 3).The geothermal system in Los Cabos is likely to be driven by heated seawater convection, as their REE concentrations are similar to those of submarine vents.

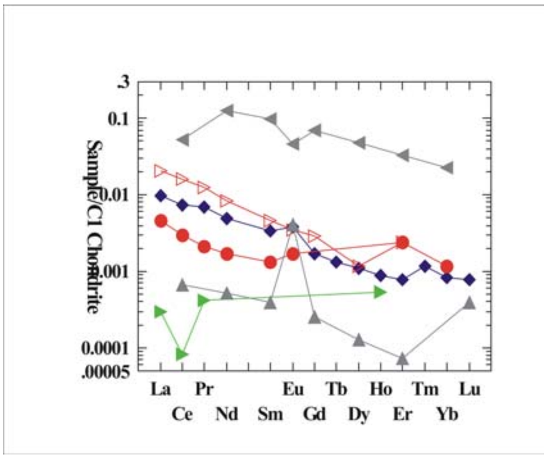

Fig. 4. REE normalized concentrations of samples LC-4 (red triangles), LC-5 (red circles), seawater (green triangles), Bahía Concepción (blue diamonds), MAR (vertical grey triangles), Valles Caldera (inclined grey triangles).

Isotopic compositions of water samples are plotted in Figure 5; the isotopic composition of deep vent water from the Guaymas Basin is included for comparison in the graph (form Campbell et al., 1988). The water samples of the cold wells and the thermal well LC-4 plot near to the meteoric line in the $\delta^{18}O$ VSMOW vs δD VSMOW graph. On the other hand, the LC-5 sample has the heaviest isotopic composition and lies in an intermediate position between samples LC-4 and LC-6 and the average isotopic composition of the deep vent water in the Guaymas Basin that is essentially heated seawater.

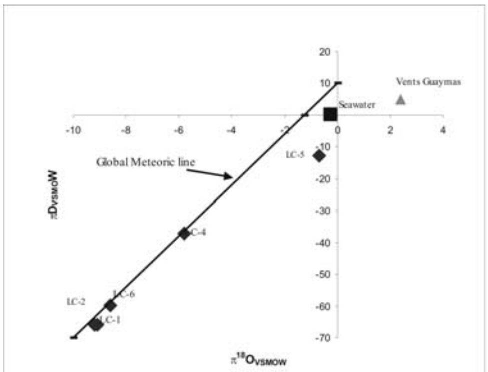

Fig. 5. Isotopic composition of the studied samples.

6. CONCLUSIONS

The chemical and isotopic characteristics of the water samples from Los Cabos are similar to those in other coastal systems in the Baja California Peninsula (Vidal et al., 1978; Prol-Ledesma et al., 2004). These coastal hydrothermal systems may constitute an important source of energy for the region, and their prospective use in seawater desalination will enhance the economic development of the Peninsula.

The results obtained from the analyses of water samples from the thermal wells indicate that they may be discharged from a reservoir with temperature close to 200°C and with seawater as the dominant fluid. This is evidence that in the vicinity there might be a high temperature hydrothermal system that could be used for production of geothermal energy.

Further work will allow calculation of the thermal end-member composition and a better estimation of the geothermal reservoir temperature.

7. ACKNOWLEDGEMENTS

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