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Geochemical Characteristics and ^{222}Rn Measurements at Cuitzeo Basin (Mexico) Thermal Springs and Artesian Wells

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ABSTRACT

Water samples from springs and wells from the Cuitzeo Basin (Michoacan state, Mexico) have been studied to investigate the main geochemical features of deep waters assessing moderate temperature geothermal resources in Mexico for direct uses. Radon measurements were also performed. Waters were classified as bicarbonate, chloride and sulfate according to their origin. Partially equilibrated and immature waters were found with reservoir temperatures ranging between 129 and 216ºC. Silica temperature results indicate that the reservoir temperatures range between 100 and 200°C. Those temperatures are useful not only for direct uses but also for the generation of electricity. The average groundwater radon concentration values were relatively low indicating an efficient fluid circulation pattern.

1. INTRODUCTION

The central region of Mexico is characterized by a volcanic range where 14 active volcanoes can be found together with lacustrine depressions where two of the main country lakes, Chapala and Cuitzeo, are located. These lakes are part of the Lerma river Basin, crossing Central Mexico from east to west, starting in the center of the country and reaching the Pacific Ocean in the west , De Cserna and Alvarez (1995) and Alfaro et al (2002).

Around the Cuitzeo depression one of the main mountains is the Los Azufres range, where the second, in electrical production, geothermal field is found (CTM, 1999). The drainage basin of Lerma river has been recognized as one of the most polluted in Mexico due to the proliferation of industrial development and the use of fertilizers and pesticides in the agricultural local practices , De Czerna and Alvarez. Recent studies (Lopez et al.(2002); Alfaro (2002) and Baca (2004)) of chemical, radioisotopic and bacteriological concentration levels in different wells and springs belonging to the Upper Lerma river basin have shown that the recharge zone is very complex.

Due to the neighboring of Los Azufres geothermal field, geochemical surveys were performed around Cuitzeo Lake since the early eighties (Tello and Quijano (1983) and Vigiano and Gutierrez (2003)). The eighties studies showed four zones interesting for geothermal uses.

In Mexico low temperature geothermal resources are slightly used for direct applications in spite of its availability in rural zones. In this paper an analysis of the possibilities of low-medium geothermal resources around Cuitzeo Lake is presented together with a geochemical and radon data interpretation.

2. SITE DESCRIPTION

Cuitzeo lake is located in the northern part of Michoacan state. Recent volcanism has occurred there. The youngest volcano, Paricutin, was born in 1943 (Figure 1). The main regional geological formations are from Tertiary and Quaternary periods. Michoacan hydrology is composed by upper Lerma River, the central lake zone and the Balsas River. The Cuitzeo basin of 3977 km^2 is one of the largest lakes of the zone. The main landform of the sampling zone is formed by the Cuitzeo depression. The southern region of the lake has been reported to have neutral-alkaline groundwater type with the recharge zones located at the border of the hills at the east of Zinapecuaro, and west of Morelia. The qualitative direction of underground flows, deduced from chemical water composition, are from south to north in the southern part of the Cuitzeo lake. At Querendaro, in the southeastern part of the lake, the flow is southeast to northwest following the local faulting (Israde-Alcantara and Garduño-Monroy, 1999; Garduño-Monroy, 1999).

The weather is moderate with summer rains (May-October) giving an average annual precipitation of 906 mm and the environmental temperature ranging from 10 to 28°C.

The western part of the Cuitzeo lake is located about 30 km from the Los Azufres geothermal field.

The geochemical and radon data were obtained from sites around the Cuitzeo lake and Los Azufres (100º 39’- 101º 20’ W and 19º 46’- 19º 59’ N) at an average altitude of 1850 m. Data came from Jeruco, Cuitzeo, Copandaro, Panteon, El Salitre, Los Baños, San Agustin del Pulque, San Juan Tararameo, San Agustin del Maiz, Araro, Mariano Escobedo and Santa Rita (Figure 1 and Table 1).

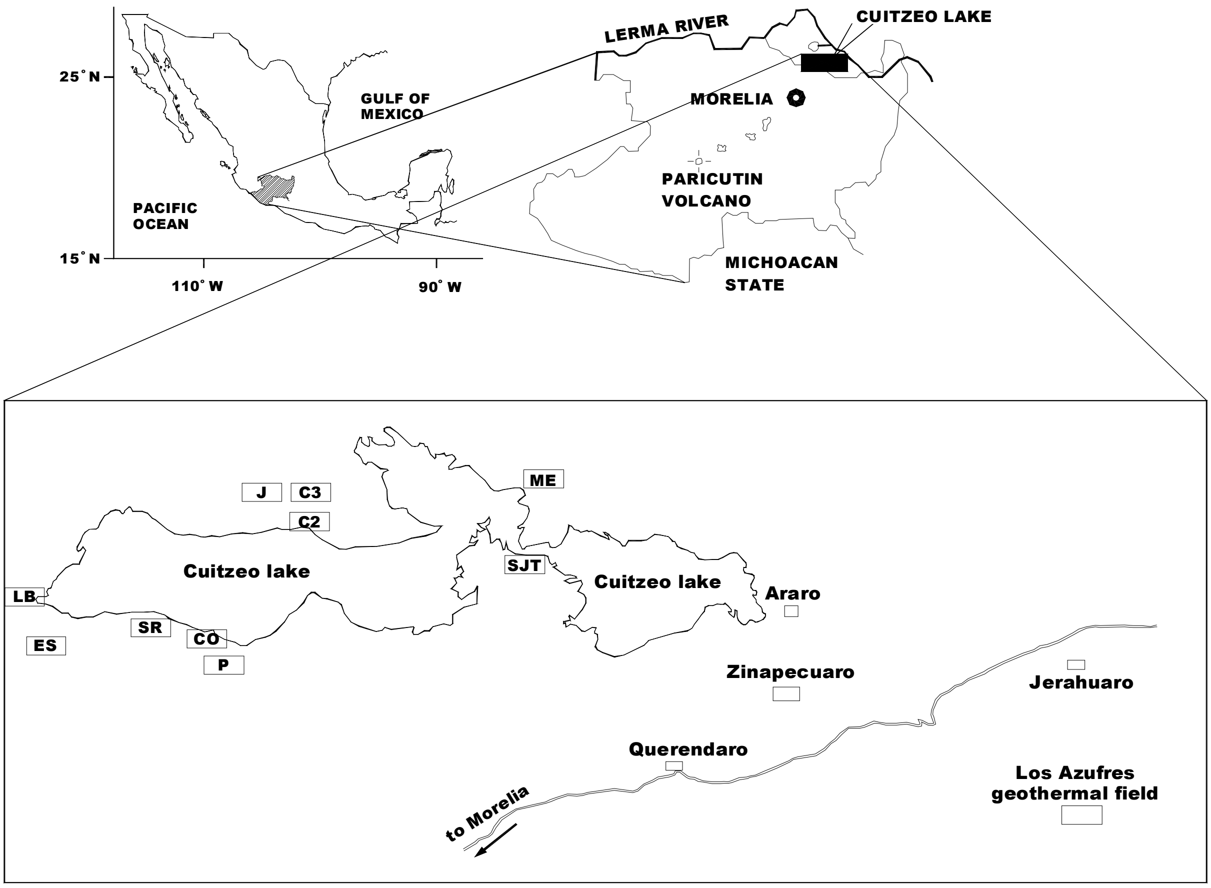

Figure 1. Location of Cuitzeo lake including several studied sites

3. METHODOLOGY

Data from 1983 (Tello and Quijano (1983) and Ramirez-Dominguez (1988)), 1990 (Viggiano and Gutierrez (2003)), 2001 (Alfaro (2002)) and 2003 (unpublished data) were analyzed to investigate the main geochemical features, the radon behavior and the estimation of reservoir temperatures.

The chemical data were classified and plotted on a Schoeller diagram (Truesdell, 1992) in order to see through the shapes of the curves if the samples are or are not related to each other.

From Giggenbach (1992) Cl^{-}-HCO_3^{-}-SO_4^{2-}, and the Na-K-Mg (modified from Giggenbach) triangular plots were also obtained for the studied sites in order to classify the waters according to the dominant ions and to estimate reservoir temperatures. The cationic composition geothermometer (CCG) was included in the Na-K-Mg plot, Giggenbach (1988) and Nieva and Nieva (1987). The silica mixing model was used to investigate the fraction of hot water in the samples.

Isotopic data from some samples were compared to the global meteoric water line and to the composition of the Los Azufres geothermal wells considering data for the natural state reservoir fluids.

Groundwater radon data were obtained during field campaigns performed each three months in 2001 and 2003 at ten monitoring stations located at the sites indicated in Figure 1.

4. RESULTS AND DISCUSSION

Chemical composition of samples is given in Table 1. Neutral to alkaline pH values were measured. Relative Cl-SO_4-HCO_3 composition for the samples is shown in Figure2, Giggenbach (1988). Only Araro samples (AR-1, AR-2) are located in the area related to “mature waters”. Steam heated waters were found at San Agustin del Pulque (SAP), San Juan Tararameo 2 (SJT-2) and San Agustin del Maiz (SAM). All the other samples are located on the bicarbonate region and they are known as “peripheral waters” due to the absorption of deep CO_2 and to the mixing with shallower waters.

Figure 3 shows the relative Na-K-Mg content for the samples, Giggenbach (1988) and Baca (2004). Groundwaters and springs are usually found close to the Mg corner while geothermal weirbox samples are found on the full equilibrium line. As shown in the Figure, only samples SAM, SAP, SJT-3 are in full equilibrium considering the CCG full equilibrium line, while AR-1, AR-2 and SJT-2 are in partial equilibrium. All the other samples correspond to “immature waters”. A mixing trend is observed among the samples indicating reservoir temperatures between 150 and 220ºC according to Giggenbach’s equilibrium line which corresponds to the range 120 to 190ºC according to CCG, Nieva and Nieva (1987).

Table 1. Physico-chemical composition of the samples. Concentrations in mg/kg, sampling temperature in ºC.

SITE	CODE	T_s	pH	Na	K	Ca	Mg	HCO_3	SO_4	Cl	B	SiO_2
JERUCO	J	25.0	8.2	130.7	17.7	58.9	45.14	414.3	99.4	52.3	0.3	68.3
CUITZEO 2	C2	26.5	8.4	56.2	14.1	37.5	37.67	372.8	41.3	8.0	0.2	67.5
CUITZEO 3	C3	27.0	8.4	29.2	7.4	32.9	32.13	303.8	3.9	4.3	0.1	64.2
COPANDARO	CO	26.0	7.7	68.9	9.3	74.3	31.69	319.8	47.2	108.0	0.2	69.4
PANTEON	PA	28.0	7.3	45.7	7.7	45.7	21.05	303.4	1.5	4.3	0.1	81.8
EL SALITRE	ES	32.0	8.0	150.7	11.5	20.6	13.70	212.1	42.7	166.5	2.2	79.9
LOS BAÑOS	LB	36.0	8.0	99.6	2.0	11.9	0.55	172.5	16.1	58.9	1.0	46.8
SAN AGUSTIN DEL PULQUE	SAP	75.0	8.0	406.0	11.0	33.0	0.20	262.0	591.0	95.8	3.0	241.0
SAN JUAN TARARAMEO 1	SJT-1	30.0	7.7	76.4	11.2	29.7	24.28	284.8	46.1	21.3		
SAN JUAN TARARAMEO 2	SJT-2	52.0	7.4	583.0	34.0	78.0	2.40	798.0	1001.0	137.0	0.1	247.0
SAN JUAN TARARAMEO 3	SJT-3	82.0	8.9	774.0	30.0	1.0	0.28	525.0	947.0	280.0	4.6	270.0
SAN AGUSTIN DEL MAIZ	SAM	89.0	7.3	542.0	27.0	14.2	0.40	623.0	591.0	130.0	3.9	250.0
ARARO 1	AR-1	60.0	7.8	691.3	55.5	26.5	0.50	134.0	138.8	1046.8	65.2	134.0
ARARO 2	AR-2	60.0	7.7	756.5	60.6	32.6	0.50	158.5	153.6	1290.2	80.4	257.5
MARIANO ESCOBEDO	ME	26.0	7.7	390.8	21.1	68.1	31.56	716.8	355.6	199.7		
SANTA RITA	SR	37.0	8.5	92.0	4.1	11.2	0.96	214.4	12.1	7.7		

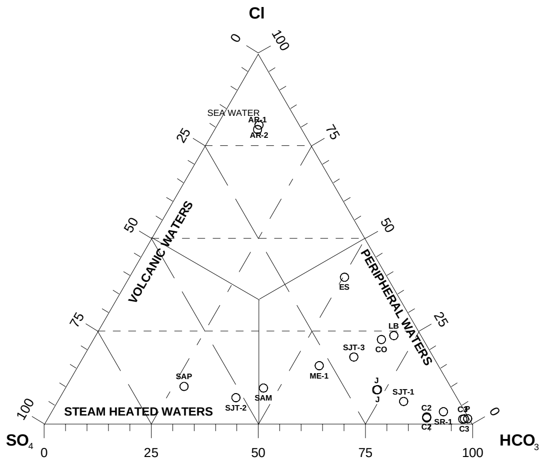

Figure 2. Relative Cl-SO_4-HCO_3 content for the samples.

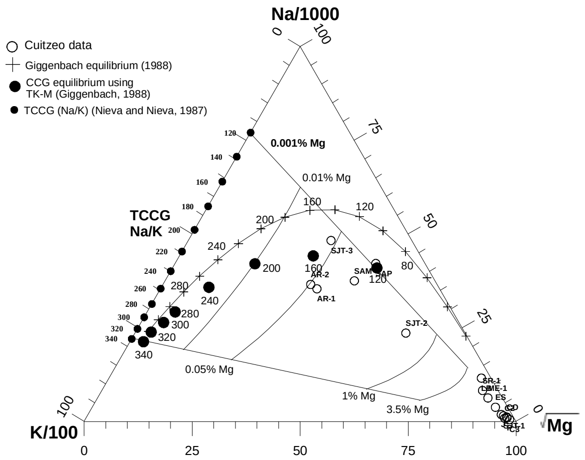

Figure 3. Relative Na-K-Mg content for the samples.

According to Schoeller diagram (Figure 4) the studied waters show different salinity and two main patterns regarding the Mg content. Low Mg waters correspond to SAM, SJT2, SJT-3, SAP, AR-1, AR-2 and SR indicating their geothermal character. The high Mg content is related to mixing with cooler and shallower waters. A wide range of SO4, Cl and B concentration values were observed among the samples. In almost all of the samples, the low Mg content corresponds to high chloride and boron contents.

Results for different geothermometers: K/Na, K/Mg, (Giggenbach (1988)); Na/K, (Fournier (1979)); Na-K-Ca (Fournier and Potter (1979)); CCG (Nieva and Nieva (1987)); SiO2 (Fournier and Potter II (1982) and Giggenbach (1988)) are given in Table 2. Cationic geothermometers provide a wide range of temperature values. Low temperature values are obtained by using geothermometers that consider Mg such as Mg correction, CCG and K/Mg. This was expected since only few samples were classified as “mature waters”. For high Mg waters a low temperature is calculated, while for low Mg high temperature is obtained. The expression for the CCG depends only on the Na/K ratio. Considering Na/K, geothermometers qualitative results were as follows: Na/K (G) provided the higher temperatures compared to Na/K (F) and these in turn gave higher temperatures than those obtained using CCG.

Figure 5 is a silica versus specific enthalpy plot, where the samples have been represented as well as the amorphous silica and quartz solubility curves. A linear tendency for the samples is observed which shows the occurrence of a mixing process. The fitted straight line for the samples was calculated by the least square method. This line is explained by assuming that the reservoir liquid at 220ºC is cooled to 131ºC by boiling and subsequently is mixed with non-thermal waters to give the sample compositions. This boiling process is shown by moving the reservoir liquid point to the hot component point. The point for separated vapor is named “Steam” in the Figure. From this diagram, the silica concentration for the reservoir liquid is estimated to be 336.4 mg/kg. The specific enthalpy was 943.6 J/g. The fraction of hot component in the samples was estimated to be about 50% in AR-2, SJT-3, SAP and SAM and around 30% for AR-1, while the rest of samples they are constituted by large fractions of shallower cooler waters.

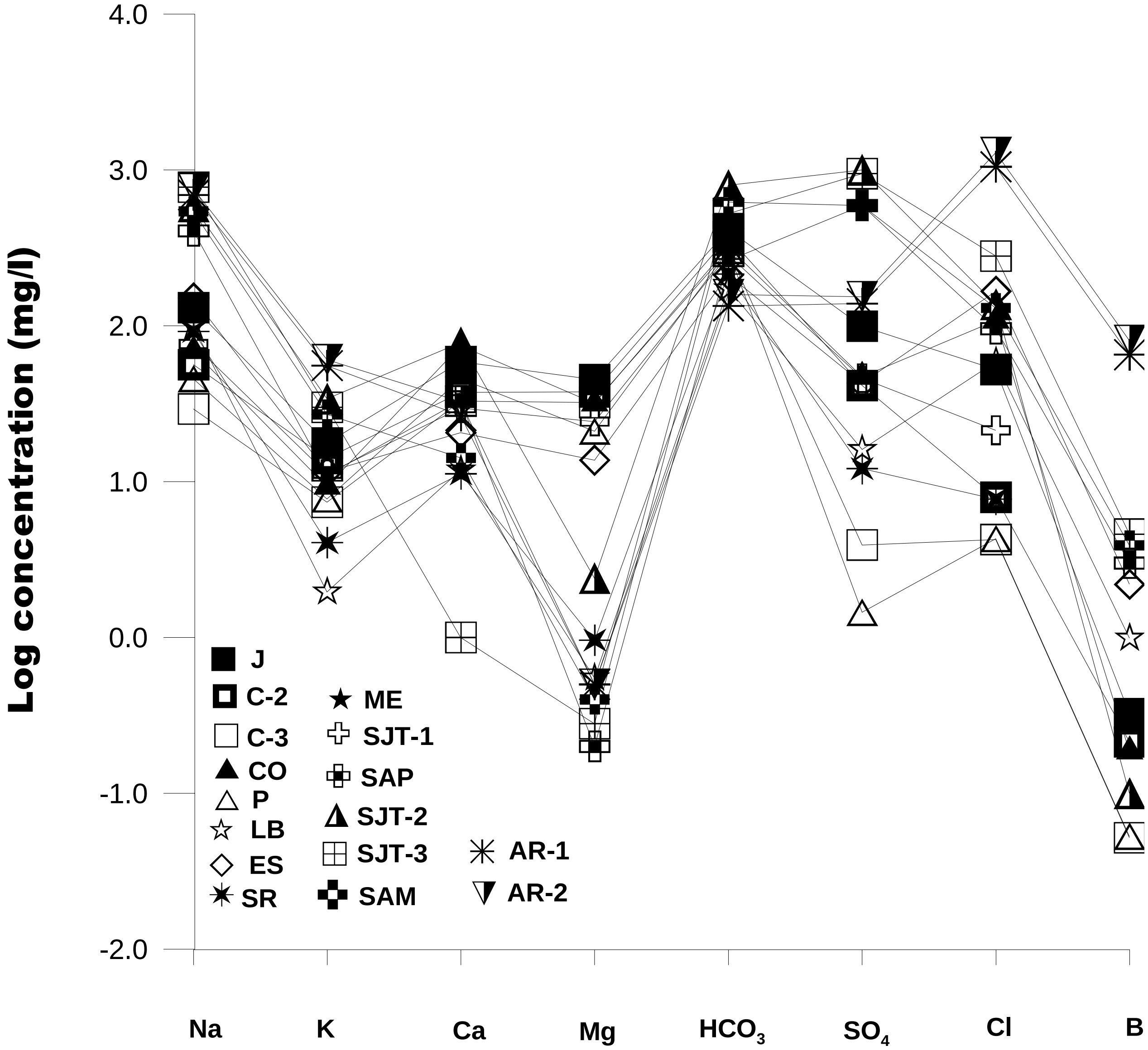

Figure 4. Schoeller diagram for the samples.

Table 2. Reservoir temperatures (ºC) estimated by different geothermometers.

CODE	T (K/Na) G	T (K/Mg) G	T (Na/K) F	T (Na/K/Ca)	T CCG	T SiO_2 (F&P)	T SiO_2 (G)
J	258	62	243	91	38	117	99
C2	318	59	309	89	38	116	95
C3	319	47	305	63	32	114	92
CO	258	52	244	64	30	118	96
PA	278	53	266	64	30	127	106
ES	212	66	195	164	42	125	105
LB	129	62	NA	58	79	99	74
SAP	146	120	NA	125	132	194	188
SJT-1	265	59	252	RLT	38		
SJT-2	193	117	175	158	163	196	191
SJT-3	167	147	NA	181	136	202	199
SAM	182	138	164	167	152	197	192
AR-1	216	159	199	192	186	156	140
AR-2	215	162	199	191	186	199	194
ME	188	70	169	153	42		
SR	175	72	156	81	105		

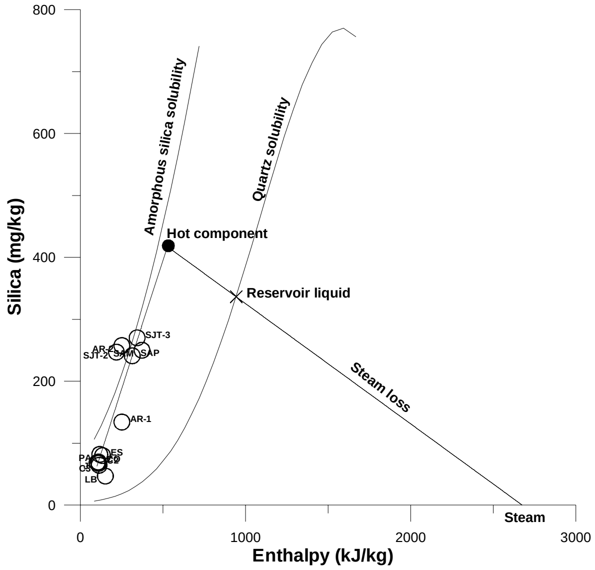

Figure 5. Specific enthalpy vs silica.

Isotopic results (δ [18] O, δD) of some springs are shown in Figure 6 where data for the Los Azufres reservoir fluids at natural state were included. All the samples show the oxygen-18 shift characteristic of geothermal fluids. Araro samples show a similar composition as compared to the Los Azufres fluids indicating a relationship between them. Tello and Quijano (1983) indicated that Araro could be a discharge of the Los Azufres fluids. The results confirm this hypothesis.

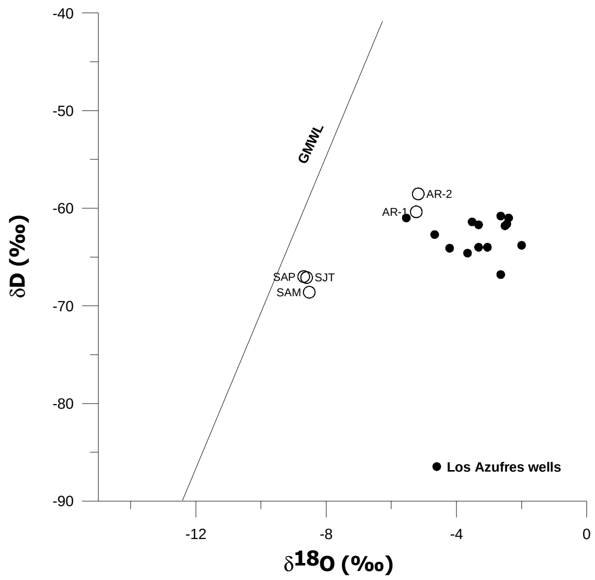

Figure 6. Deuterium vs oxygen-18 of some samples.

The average and standard deviation of groundwater radon concentration values for each monitoring station are shown in Figure 7. The average radon concentration values ranged from 0.88 to 3.66 BqL^{-1}. These values, which are relatively low, indicate a rapid transit from recharge to the output of springs and wells (Baca et al. (2004)) even if the stations are located in different geological environments around the lake. Effectively, stations Jeruco (J), Cuitzeo-2 (C2) and Cuitzeo-3 (C3) are located on pyroclastic flow deposits from local monogenetic volcanism at the northwestern shore of the lake. Station San Juan Tararameo (SJT) at the central part of the lake corresponds to lacustrine deposits. Santa Rita (SR) and Copandaro (CO) are located on andesitic rocks in the southern part of the lake. However, all of them are associated to normal faulting that form the semi-graben of Cuitzeo lake.

It is worth mentioning that the lower radon values in groundwater were found at El Salitre (ES), Copandaro (CO) and Mariano Escobedo (ME), which are the three stations located on one of the main local geological faults. This behavior is explained by occurring of the gas emanations at these sites. As radon is partitioned to the gas phase the liquid phase becomes depleted.

The higher radon values correspond to the sites where higher reservoir temperatures and gas emanations were found due to the high efficiency fluid flow that eventually transports the radon to the surface.

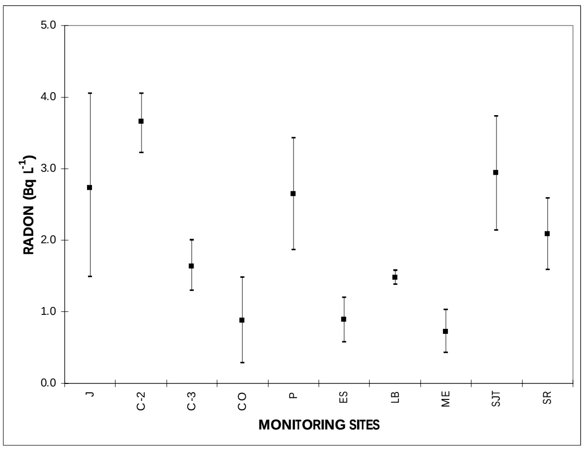

Figure 7. Radon concentration values.

In Table 3, the possible alternative uses of geothermal energy as a function of reservoir temperature are given. For the studied sites temperatures, there are many possible applications of geothermal fluids, including electric generation by conventional or binary cycles.

5. CONCLUSIONS

Analysis of chemical data from Cuitzeo wells and springs suggests that one or more geothermal reservoirs could occur. Araro waters are probably related to the Los Azufres geothermal fluids. Chemical geothermometers provided a wide range of temperatures for the reservoir, from 165 to 220ºC, which enabled electric generation and a wide range of direct applications. A model based on silica and enthalpy was obtained indicating a mixing process between hot deep fluids with shallower, cooler waters in different proportions. AR-2, SAM, SAP and SJT samples present about 50% of hot component in the mixture. Radon results indicated a high efficient fluid flow transport in the zones where higher reservoir temperatures were estimated.

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Table 3. Uses of geothermal energy (Lindall, 1973)

Source temperature (°C)	Potential uses
180	Evaporation of highly concentrated solutions Refrigeration by ammonia absorption, Digestion paper pulp, Kraft
170	Heavy water via hydrogen sulfide process, Drying of diatomaceous earth
160	Drying of fish meal, Drying of timber
150	Alumina via Bayer´s process
140	Drying farm products at high ratesCanning of food
130	Evaporation in sugar refining, Extraction of salts by evaporation and crystallization
120	Fresh water by distillation, Most multiple effect evaporations, concentration of saline solutions
110	Drying and curing of light aggregate cement slabs
100	Drying of organic materials, seaweeds, grass, vegetables, etc., Washing and drying of wool
90	Drying of stock fish, Intense de-icing operations
80	Space heating, Greenhouses by space heating
70	Refrigeration (lower temperature limit)
60	Animal husbandry, Greenhouses by combined space and hotbed heating
50	Mushroom growing, Balneologicaal baths
40	Soil warming
30	Swimming pools, biodegradation, fermentations, Warm water for year-round mining in cold climates,De-icing
20	Hatching of fish, fish farming

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