

# Determination of radon, major and trace elements in water samples from springs and wells of northern Mexico State, Mexico

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Received: September 4, 2001; accepted: February 27, 2002.

## RESUMEN

Se determinaron radón, componentes químicos mayores y elementos traza en muestras de agua de cuatro manantiales y tres pozos de zonas urbanas y agrícolas de la parte media del Eje Neo-Volcánico Mexicano. El <sup>222</sup>Rn se midió por el método de centelleo líquido; el análisis de componentes mayores se realizó con técnicas químicas convencionales, mientras que los elementos traza se cuantificaron utilizando un ICP-MS. Los valores promedio de la concentración de radón obtenidos durante un año fueron relativamente bajos, entre 0.97 y 4.99 Bq L<sup>-1</sup>, indicando un transporte rápido desde el área de recarga hasta los puntos de muestreo. Los componentes mayores y los elementos traza mostraron diferencias que indican orígenes distintos del agua de los sitios en estudio.

**PALABRAS CLAVE:** Química de agua subterránea, radón, compuestos mayores y elementos traza, zonas volcánicas.

## ABSTRACT

Radon was determined in four springs and three wells from urban and agricultural zones in the middle part of the Mexican Neovolcanic Belt. Major and trace elements were also determined in the water samples. The measurement techniques included the liquid scintillation method for <sup>222</sup>Rn, conventional chemical analyses for major components and ICP-MS for metallic trace elements. The average radon concentration values were relatively low ranging from 0.97 to 4.99 Bq L<sup>-1</sup> indicating a rapid transit from recharge area to the output of the springs. The major and trace elements showed differences in the origin of water for the studied sites.

**KEY WORDS:** Groundwater chemistry, radon, major and trace elements, volcanic zone.

## INTRODUCTION

Groundwater may contain high amounts of natural radioactivity mainly associated with uranium and thorium-rich soils and rocks, while surface water usually contains lower amounts of <sup>222</sup>Rn than groundwater (Annanmaeki *et al.*, 2000). Groundwater <sup>222</sup>Rn concentration fluctuations can give information on water origin, flow mechanisms, local hydrogeological characteristics and hydraulic properties of aquifers (Segovia *et al.*, 1999). Assessment of the natural background, or the geochemical baseline, of major and trace elements in surface and groundwaters is of paramount importance to reconcile the exploitation of natural resources with the protection of the environment, including the health of human beings and animals. Knowledge of the major element content of water samples allows plausible speculation

on its origin and history. However, the trace elements dissolved in groundwater have shown to be even more significant than the major element content to determine the pathway of recharge and the local geology influence on the water quality (Marini *et al.*, 2001). When groundwater containing natural radionuclides is used for drinking or in water treatment, inhalation, etc., the radiation dose in humans using these water sources has also a known importance in epidemiological studies (Cosma, 2000).

The Upper Lerma river basin is located in the State of Mexico, Mexico. The region belongs to the middle part of the Mexican Neovolcanic Belt. Previous studies of natural radionuclides and physical and chemical parameters of groundwater samples from boreholes belonging to the drinking water supply of Toluca, the capital city of the State of

Mexico, have shown different radon concentrations depending on the local or regional groundwater flow (Olguin *et al.*, 1993; Segovia *et al.*, 1999).

With the aim to determine radionuclide and chemical characteristics of springs and wells of a zone belonging to the recharge area of the Toluca valley aquifers, radon, major and trace elements were determined at springs and wells used for drinking water supply, located in urban and agricultural zones near Jocotitlan volcano and El Oro mining region in the northern part of the State of Mexico.

### Site description

The area is dominated by two main landforms: the mountainous one being a result of intensive recent volcanic activity, and an alluvial valley between the mountain ranges where Lerma river flows from SE to NW (Figure 1). Several springs and wells are located in the region. Those springs discharge into the Upper Lerma river. The sampling sites are located in the northern part of the State of Mexico, between 19°40'19'' and 19°50'43'' N and 99°41'05'' and 100°08'24''W, at altitudes between 2562 and 2818 masl. The Lerma river divides the two zones of the present study, the western mountainous range where El Oro is located and, to the east, the Jocotitlan volcano (Figure 1).

**El Oro** is a volcanic zone that was an important gold, silver and zinc mining area one hundred years ago. The geology includes alluvial Quaternary soil and Tertiary igneous extrusive rocks such as andesite, basalt, acid tuff and volcanoclastic material (INEGI, 1999). The zone is surrounded by oaks and coniferous forests and the agriculture is basically corn, wheat and beans. Four sampling sites were selected at El Oro area:

**Sta. Cruz**, a spring having 17.3 °C average temperature; it is downtown El Oro City and the water is used as local drinking water supply.

**Cuauhtemoc** is an artesian well, 7 m depth having 15.8 °C average temperature. It is located in a farm in a valley where the main production is corn.

**La Venta** is a borehole near El Oro City, with 20.4 °C average temperature.

**Tultenango**, a borehole 280 m deep having a 44 Ls<sup>-1</sup> flow, with average temperature of 24.2 °C, located in a valley where the main activity is agriculture and animal breeding.

**Jocotitlan** is one of the main volcanoes of the zone.

The local geology has Tertiary volcanoclastic rocks, andesites and extrusive igneous rocks. Three sampling sites were selected at the bottom of the volcano area:

**Las Fuentes**, is a group of springs used for local drinking water supply, the average temperature is 18 °C.

**Tiacaque**, a spring where the water is stored in a container and pumped for local drinking water supply; the average temperature is 18 °C.

**Pasteje** a spring located in an agricultural and animal breeding area of an industrial zone. The water is used for local drinking water supply; the average temperature is 18.3 °C.

### Experimental

**Sampling.** Monthly sampling of water for radon determination was carried out from February 2000 to February 2001 using carefully cleaned containers. In filling the containers, care was taken to avoid air bubbles and sealing of the bottles was performed in order to avoid degassing. Aliquots of 100 ml sample and 10 ml pure toluene were transferred to a separator funnel and vigorously shaken for 5 minutes for radon separation. When the mixture resettled in two phases, the organic phase was transferred into a counting vial to which 10 ml of INSTAGEL scintillation solution was added (Olguin *et al.*, 1993).

One litre water samples were taken in plastic polyethylene bottles for major chemical components such as Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, and SiO<sub>2</sub>. A 500 ml sample having 3 ml HNO<sub>3</sub> was used for the analysis of Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup> and Mg<sup>2+</sup>.

The sampling for trace elements dissolved in the water was performed in 60 ml HDPE bottles previously washed and decontaminated. One day before the sampling the bottles and covers were rinsed three times and filled with deionized water. In the field two samples were taken at each place, one with the water sample and the other with deionized water used as a field blank. The samples were filtered under a laminar flow hood and acidified with ultrapur HNO<sub>3</sub> (1% v/v).

### Measurement techniques

**Radon.** The water samples were analysed for solubilized <sup>222</sup>Rn with a Packard TRI-CARB 2700TR scintillation detection system. The results are reported in Bq L<sup>-1</sup>. Corrections for decay of radon and decay and growth of the daughter products in the samples were necessary (Olguin *et al.*, 1993).

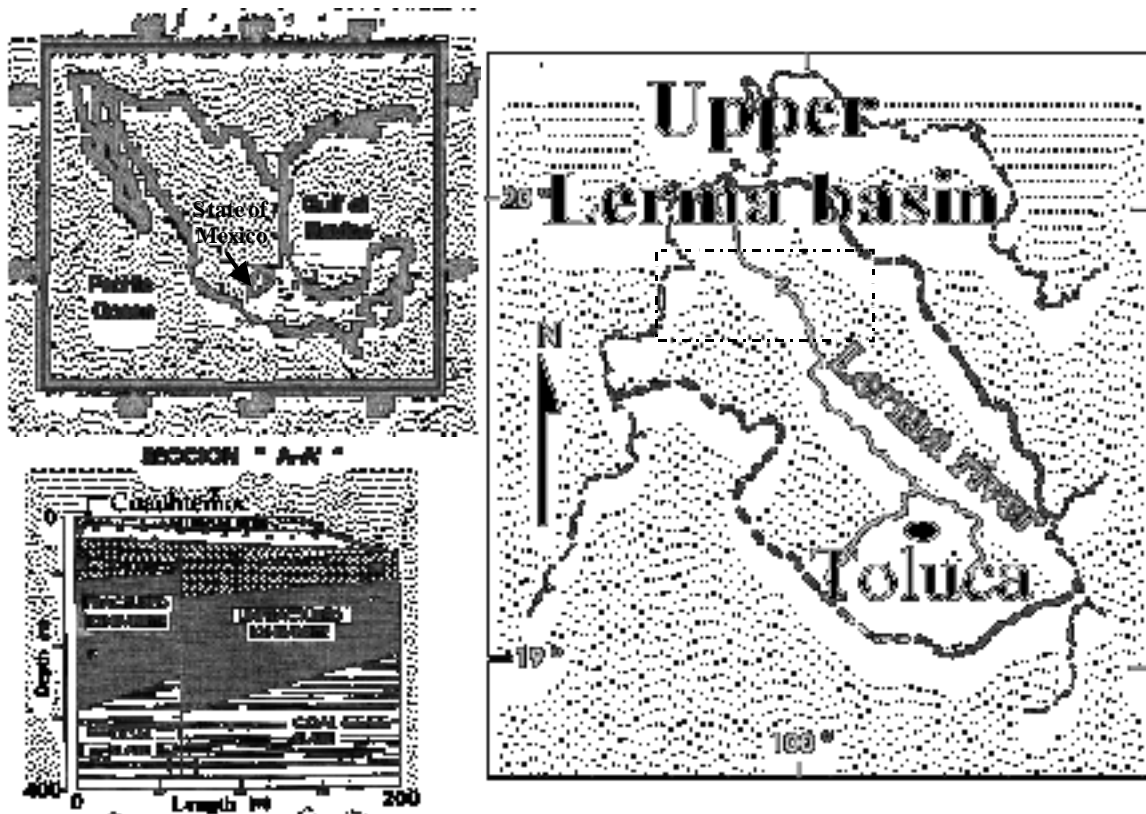


Fig. 1. Location of the sampling sites in the northern part of the State of Mexico.

*Physical and chemical parameters.* In the field, electrical conductivity was determined with a conductimeter (Conductronic PC18). Temperature and pH were determined with a Schott pH-Meter CG 837, calibrated before each measurement using 4 pH buffer solution.

Chemical analyses for major elements were performed by standard methods, as given in APHA-AWWA-WPCF

(1995). The accuracy of the analyses was checked by the ionic charge balance (lower than 4% difference).

Trace elements were determined at  $\mu\text{g L}^{-1}$  levels using an ICP-MS (Inductively Coupled Plasma Mass Spectrometer) VG Plasma Quad 2 Turbo Plus from the University of Montpellier 2, France. Calibration was performed with 5 and 10  $\mu\text{g L}^{-1}$  solution containing all the elements to be analysed.

A 10  $\mu\text{g L}^{-1}$   $^{115}\text{In}$  and  $^{209}\text{Bi}$  solution was used as internal standard in order to correct instrumental drift (Morton *et al.*, 1998).

### RESULTS AND DISCUSSION

The radon content from the 7 sites is shown in Figure 2. The average values were: Sta Cruz ( $1.51 \pm 0.46 \text{ Bq L}^{-1}$ ), Cuauhtemoc ( $4.99 \pm 1.37 \text{ Bq L}^{-1}$ ), La Venta ( $1.74 \pm 0.56 \text{ Bq L}^{-1}$ ), Tultenango ( $1.22 \pm 0.32 \text{ Bq L}^{-1}$ ), Las Fuentes ( $0.97 \pm 0.32 \text{ Bq L}^{-1}$ ), Tiacaque ( $1.79 \pm 0.42 \text{ Bq L}^{-1}$ ) and Pasteje ( $1.27 \pm 0.45 \text{ Bq L}^{-1}$ ).

The highest maximal ( $6.81 \text{ Bq L}^{-1}$ ) and average ( $4.99 \text{ Bq L}^{-1}$ ) radon concentration were found at Cuauhtemoc well. The maxima occurred from July to October during the rainy season. Cuauhtemoc site seems to be very sensitive to the direct rain effect. This well is an artesian one, opened to the atmosphere with a water level varying from 1.5 m depth during the rainy season (August-September) to 7 m depth during the dry season (April, May). This effect of radon enhancing with cumulative precipitation was also reported by Hamada (2000). The aquifer seems to respond to a percolating effect that increases the groundwater radon. It is worth mentioning that the local geology has a shallow tuff and soil layer underlain by andesite (Figure 1). This particular configuration eases the emanation of radon into the

percolating water, in contrast with the other sites where the radon content was quite stable along the year indicating a rapid transit from recharge areas to the springs. It has been reported that the region has had an intense volcanic activity from the Tertiary to recent times and geological units show zones with diverse degrees of fracturation. Consequently different radionuclide concentrations could be related to preferential groundwater flows through acidic or basic rocks of the area (Segovia *et al.*, 1999). Groundwater flow influences hydrochemical patterns because flow reduces mixing processes, carries the chemical imprints of biological and anthropogenic changes in the recharge area and leaches the aquifer system (Stuyfzand, 1999). Temperature values varied all over the year from  $16\text{ }^\circ\text{C}$  to  $25\text{ }^\circ\text{C}$  however radon was quite stable in almost all the studied periods and sites.

The Piper Diagram for the studied waters is shown in Figure 3, indicating that the sampled waters are of Ca-Mg- $\text{HCO}_3$  type. Some authors indicate (Marini *et al.*, 2001) that Ca- $\text{HCO}_3$  waters result from shallow short lived hydrogeological pathways. This concept agrees with the low observed radon and indicate a rapid transit of groundwaters in the zone.

In Table 1, an example of the major species and trace elements content in the water samples determined at each site is shown. Classical correlation matrices (Table 2), were

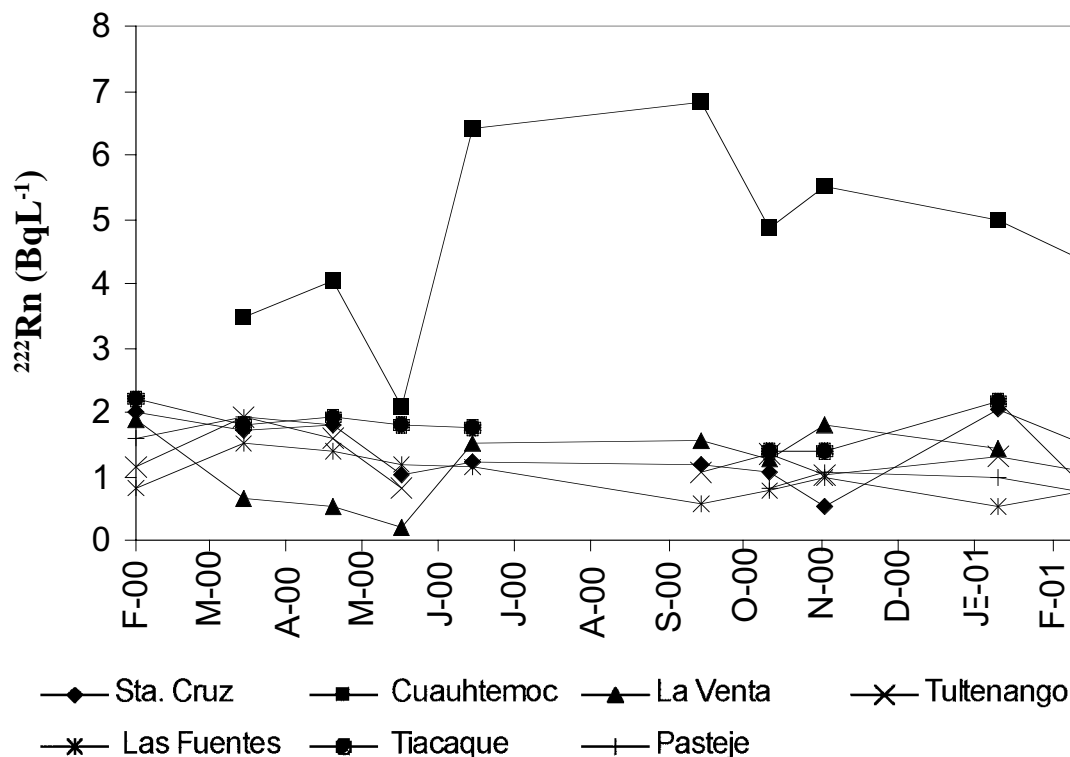


Fig. 2.- Radon concentration values ( $\text{Bq L}^{-1}$ ) at S. Cruz, Cuauhtemoc, La Venta and Tultenango (El Oro zone); Las Fuentes, Tiacaque and Pasteje (Jocotitlan volcano zone), from February 2000 to February 2001.

Table 1

An example of major and trace elements from different samplings at El Oro and Jocotitlan springs and wells. The number relied to the site indicate the sampling code.

**Major species ( mg L<sup>-1</sup> )**

Area	Location	Temp. °C	pH	EC μS/cm <sup>-1</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup>	F <sup>-</sup>	SiO <sub>2</sub>
El Oro	Sta. Cruz 2	18	6.58	198	18.3	8.9	13.3	7.4	6	19.4	91.4	0.1	67.6
	Cauhtemoc 3	14	6.11	91	8.9	5.4	2.4	1.3	4.1	-	35.2	0.1	28.3
	La Venta 4	20	7.58	235	24.0	7.8	13.4	4.9	2.1	-	148.0	0.2	65.4
	Tultenango 5	25	7.46	329	25.1	11.6	26.1	8.8	1.7	4.3	210.5	0.3	69.9
Jocotitlan Volcano	Las Fuentes 4	18	7.75	131	7.9	7.1	9.7	1.6	1.8	4.2	70.6	0.3	52.1
	Tiacaque 2	16	6.92	163	11.8	8.4	10.1	1.8	9	10.6	60.4	0.3	52.2
	Pasteje 3	18	7.07	263	16.7	11.9	15.1	5.4	8.2	25.7	76.6	0.3	57.4

**Trace elements ( μg L<sup>-1</sup> )**

Area	Location	Li	B	Mn	Co	Cu	Zn	As	Rb	Sr	Mo	Cd	Cs	Ba	Pb	U
El Oro	Sta. Cruz 1	3.696	13.223	0.695	0.121	0.152	3.978	0.402	13.179	361.02	0.792	0.049	0.137	85.845	0.363	0.797
	Cauhtemoc 1	0.330	18.670	4.388	0.056	1.667	99.840	0.120	4.459	153.79	0.071	0.129	0.028	11.605	0.509	0.001
	La Venta 1	10.801	16.978	0.075	0.814	0.741	3.350	1.466	9.413	198.97	1.109	0.016	0.237	37.591	0.005	0.213
	Tultenango 2	10.725	11.419	0.163	0.050	3.980	111.01	6.895	15.311	268.73	0.528	0.024	0.332	66.030	0.543	1.910
Jocotitlan Volcano	Las Fuentes 1	7.927	15.810	0.741	0.390	2.046	8.615	1.254	6.767	66.115	0.700	0.392	0.298	6.512	0.540	0.096
	Tiacaque 2	5.067	17.547	0.780	0.420	1.105	15.201	1.197	6.374	91.652	0.733	0.382	0.257	18.444	0.432	0.078
	Pasteje 2	1.772	17.290	0.862	0.166	0.483	4.288	0.369	12.248	192.95	0.405	0.214	0.195	72.25	0.458	0.098

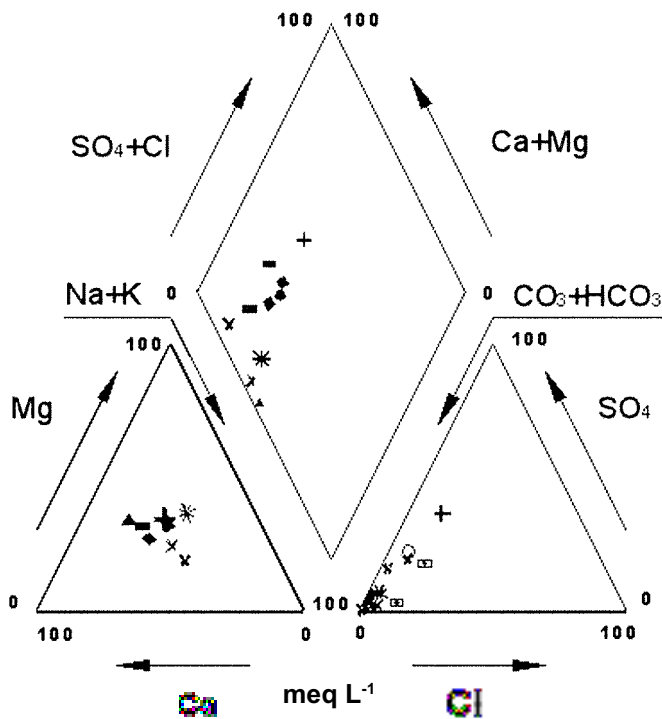


Fig. 3. Piper diagram from the studied sites. The signs are the same as in Fig. 2 for each one of the wells and springs.

used with all the data available during one year. Elements showing  $r > 0.7$  are defined to be strongly correlated whereas  $r = 0.5 - 0.7$  shows moderate correlation.

For both major species and trace elements strong correlations showed marked differences between el Oro and Jocotitlan areas. Both areas had strong positive correlations between the major exchangeable species Na, Mg, Ca, K, and a strong negative correlation between Cl-Fe.

It has been mentioned (Adams *et al.*, 2001) that pH determine the mobility and solubility of F, and Cl, Ca, Mg, Na and SO<sub>4</sub> are the main contributors to the groundwater salinity. In the present results F had average values of 0.08, 0.116, 0.157 and 0.2 mg L<sup>-1</sup> at Sta Cruz, Cauhtemoc, La Venta and Tultenango respectively, where the pH average values were 6.59, 6.45, 6.9 and 7 respectively, indicating that higher pH corresponded to higher F concentration. At Tiacaque, Pasteje and Las Fuentes the average pH (6.1, 6.7, 7.1 respectively) and F (0.1, 0.154., and 0.2 mg L<sup>-1</sup> respectively) indicate the same pattern between pH and F as found for El Oro groundwaters. Additionally the main exchange elements Ca, Mg and Na correlate positively especially at

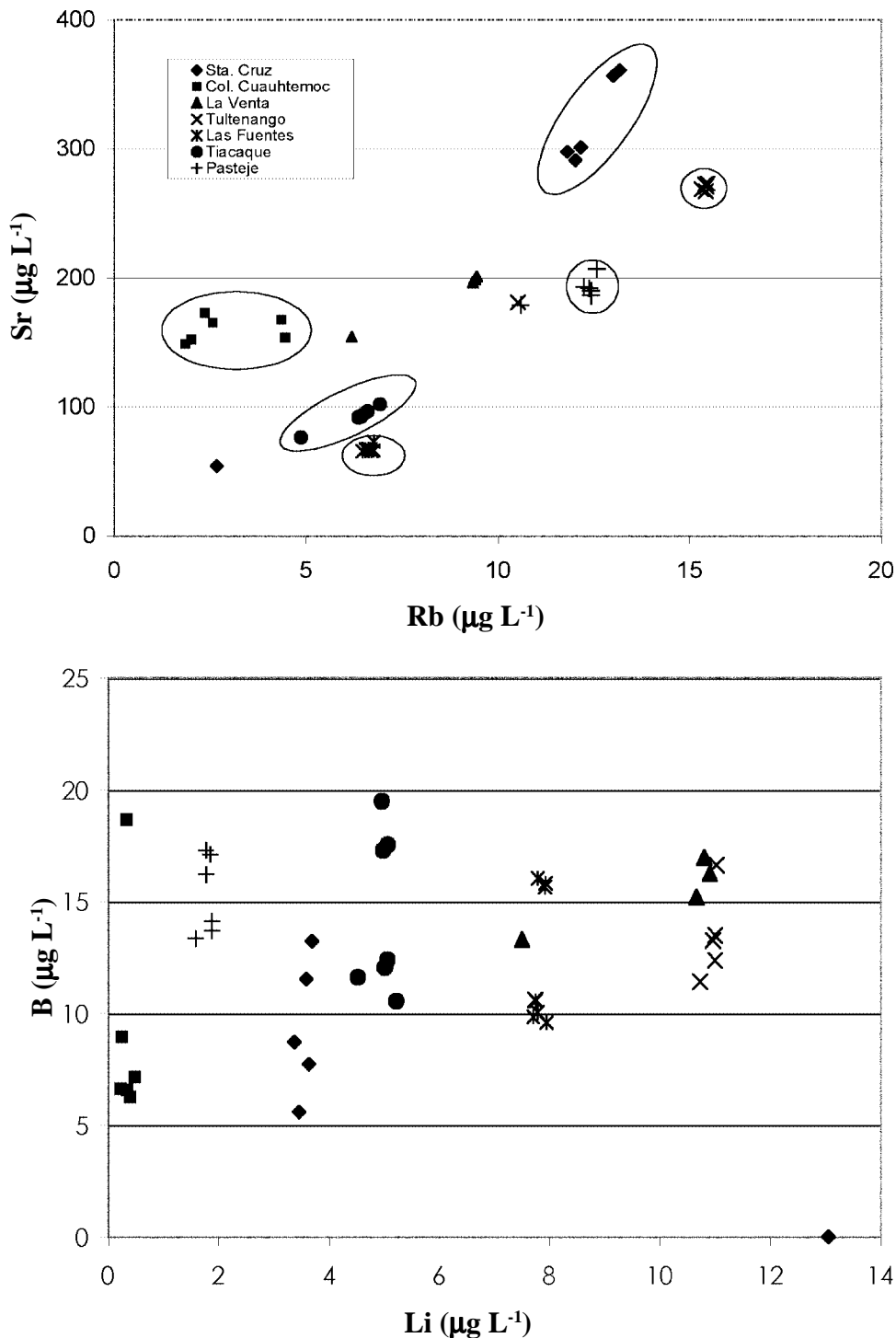


Fig. 4. Bimodal diagrams Rb-Sr and Li-B for the studied wells and springs.

Pasteje, Tiacaque and Las Fuentes springs indicating the influence of the geological volcanic matrix associated with the Jocotitlan volcano.

Both areas had strong positive correlations for the trace elements As-Li, Li-Cs, Cr-Co, Cr-Cd, Co-Cd, As-Cs, Rb-Sr,

Rb-Ba and Sr-Ba. A moderate positive correlation was only found for Cu-Pb at the two sites. No common strong and moderate negative correlations were found for the two areas. El Oro and Jocotitlan showed marked differences in the geochemical baselines, particularly when trace elements are concerned, indicating differences in the water origin.

Table 2

Correlation matrices for major species and trace elements in the water samples from El Oro and Jocotitlan volcano areas.

**Major species correlation matrices: El Oro**

	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	PO <sub>4</sub> <sup>3-</sup>	F <sup>-</sup>	Fe <sup>2+</sup>	SiO <sub>2</sub>
Ca <sup>2+</sup>	1											
Mg <sup>2+</sup>	0.9481	1										
Na <sup>+</sup>	0.6844	0.5796	1									
K <sup>+</sup>	0.9115	0.9181	0.6067	1								
Cl <sup>-</sup>	-0.2106	-0.1754	0.3354	-0.2451	1							
SO <sub>4</sub> <sup>2-</sup>	-0.0156	0.1236	-0.0082	0.1924	0.1127	1						
HCO <sub>3</sub> <sup>-</sup>	0.5241	0.5670	-0.1429	0.4569	-0.5270	-0.0182	1					
NO <sub>3</sub> <sup>-</sup>	0.1985	0.1631	-0.0030	0.2481	-0.5457	0.5231	0.1276	1				
PO <sub>4</sub> <sup>3-</sup>	-0.4425	-0.3641	-0.3402	-0.5186	0.3507	-0.0803	-0.2002	-0.0470	1			
F <sup>-</sup>	0.3118	0.4059	-0.2571	0.3066	-0.5427	-0.1282	0.8823	-0.1124	-0.3457	1		
Fe <sup>2+</sup>	0.4097	0.4261	-0.1983	0.5311	-0.8288	0.1673	0.5471	0.6781	-0.1701	0.3817	1	
SiO <sub>2</sub>	0.1326	0.2351	0.4266	0.4404	0.3761	0.3037	-0.2895	-0.1654	-0.1164	-0.2053	-0.0667	1

**Jocotitlan**

	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	PO <sub>4</sub> <sup>3-</sup>	F <sup>-</sup>	Fe <sup>2+</sup>	SiO <sub>2</sub>
Ca <sup>2+</sup>	1											
Mg <sup>2+</sup>	0.9999	1										
Na <sup>+</sup>	0.9492	0.9535	1									
K <sup>+</sup>	0.9585	0.9624	0.9995	1								
Cl <sup>-</sup>	0.9997	0.9993	0.9415	0.9516	1							
SO <sub>4</sub> <sup>2-</sup>	0.9988	0.9981	0.9330	0.9437	0.9997	1						
HCO <sub>3</sub> <sup>-</sup>	0.9848	0.9872	0.9894	0.9934	0.9805	0.9753	1					
NO <sub>3</sub> <sup>-</sup>	-0.7289	-0.7193	-0.4764	-0.5036	-0.7448	-0.7610	-0.5991	1				
PO <sub>4</sub> <sup>3-</sup>	-0.7289	-0.7193	-0.4764	-0.5036	-0.7448	-0.7610	-0.5991	1.0000	1			
F <sup>-</sup>	-0.8183	-0.8102	-0.5958	-0.6206	-0.8316	-0.8450	-0.7062	0.9900	0.9900	1		
Fe <sup>2+</sup>	-0.7289	-0.7193	-0.4764	-0.5036	-0.7448	-0.7610	-0.5991	1.0000	1.0000	0.9900	1	
SiO <sub>2</sub>	0.9292	0.9239	0.7657	0.7854	0.9376	0.9459	0.8510	-0.9303	-0.9303	-0.9728	-0.9303	1

**Trace elements correlation matrices: El Oro**

	Li	B	Cr	Mn	Co	Cu	Zn	As	Rb	Sr	Mo	Cd	Cs	Ba	Pb	U
Li	1															
B	-0.0730	1														
Cr	0.0619	-0.7556	1													
Mn	-0.2655	0.6781	-0.3050	1												
Co	-0.3969	-0.7500	0.8535	-0.2608	1											
Cu	0.2819	-0.1430	-0.0307	0.0740	-0.2560	1										
Zn	-0.1795	-0.1934	0.1649	0.5204	0.2449	0.4864	1									
As	0.9663	0.0365	0.0479	-0.2321	-0.4540	0.3072	-0.3020	1								
Rb	0.8304	-0.4701	0.2634	-0.4856	-0.0094	0.0902	-0.0128	0.6764	1							
Sr	0.2122	-0.6448	0.2478	-0.5446	0.3702	-0.2624	0.1011	-0.0172	0.7126	1						
Mo	0.4392	-0.3519	-0.0863	-0.7215	-0.0665	-0.3140	-0.4078	0.2895	0.7264	0.8145	1					
Cd	-0.5144	-0.5784	0.7770	0.0713	0.9247	-0.0571	0.5037	-0.5456	-0.2239	0.1153	-0.4051	1				
Cs	0.9885	-0.0884	0.0410	-0.2005	-0.3970	0.3481	-0.0409	0.9279	0.8514	0.2572	0.4235	-0.4846	1			
Ba	0.4829	-0.4262	0.0012	-0.3627	0.0012	0.0054	0.2169	0.2474	0.8390	0.8966	0.7886	-0.1786	0.5566	1		
Pb	-0.1462	-0.1134	0.0471	0.5491	0.1267	0.5206	0.9920	-0.2709	-0.0077	0.0835	-0.3834	0.3943	-0.0026	0.2442	1	
U	0.9629	0.0461	-0.1843	-0.2233	-0.5791	0.3370	-0.1558	0.9125	0.7892	0.2179	0.4937	-0.6784	0.9687	0.5483	-0.0922	1

**Jocotitlan**

	Li	B	Cr	Mn	Co	Cu	Zn	As	Rb	Sr	Mo	Cd	Cs	Ba	Pb	U
Li	1															
B	-0.3556	1														
Cr	0.8334	0.0991	1													
Mn	-0.6653	0.2117	-0.5293	1												
Co	0.8429	0.1155	0.9957	-0.4990	1											
Cu	0.8586	-0.3617	0.7115	-0.5094	0.7305	1										
Zn	0.4284	-0.0293	0.6214	-0.1015	0.6053	0.5953	1									
As	0.8803	-0.0395	0.9581	-0.4120	0.9674	0.7618	0.6038	1								
Rb	-0.8621	-0.0709	-0.9956	0.5187	-0.9984	-0.7388	-0.5887	-0.9727	1							
Sr	-0.9525	0.1260	-0.9560	0.5972	-0.9626	-0.8247	-0.5402	-0.9598	0.9725	1						
Mo	0.4133	0.6373	0.6947	-0.5186	0.7057	0.3610	0.2788	0.5432	-0.6814	-0.5809	1					
Cd	0.7818	0.0274	0.9288	-0.3821	0.9361	0.8342	0.7387	0.9359	-0.9335	-0.8992	0.6037	1				
Cs	0.9853	-0.2682	0.8934	-0.6158	0.9032	0.8874	0.5064	0.9358	-0.9182	-0.9784	0.4796	0.8730	1			
Ba	-0.9441	0.0933	-0.9653	0.6013	-0.9710	-0.8137	-0.5374	-0.9647	0.9800	0.9989	-0.6064	-0.9060	-0.9746	1		
Pb	0.3405	-0.4601	0.2983	0.0424	0.2970	0.5612	0.2871	0.3816	-0.3192	-0.3593	-0.1901	0.4872	0.4110	-0.3486	1	
U	0.1034	-0.8201	-0.3356	0.1850	-0.3236	0.1863	0.0933	-0.1553	0.3018	0.1227	-0.7537	-0.2122	0.0108	0.1621	0.1885	1

Examples of bimodal diagrams Li-B and Rb-Sr (Figure 4) indicate that each well or spring content differentiates. At El Oro region, considering the Li-B relation, La Venta and Tultenango boreholes had the same Li values, while Sta Cruz and Cuauhtemoc had almost the same B values. For the Jocotitlan area, the three springs had almost the same B content and different Li values increasing from 2  $\mu\text{g L}^{-1}$  at Pasteje to 8  $\mu\text{g L}^{-1}$  at Las Fuentes. The Rb-Sr patterns are also individualised for each well and spring. However a less differentiation is observed between the two areas. Only Tiacaque and Las Fuentes springs, from the Jocotitlan area, exhibit small concentrate variations.

The complexity of the recharge zone of the Upper Lerma river indicates the importance to study the groundwater conditions of the zone. It is worth remembering that the drainage basin of Lerma river is one of the most polluted in Mexico (De Czerna and Álvarez, 1995) and yet no sound solution, including environmental and geologic aspects, has been attempted to protect the region.

#### ACKNOWLEDGMENTS

The authors acknowledge D. Cruz, S. Ceballos, N. Cenicerros, O. Cruz and A. Aguayo for technical assistance. This study was carried out with partial financial support from CONACyT project 32467-T.

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