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A SURVEY OF GROUNDWATER FLOW USING DEUTERIUM AND OXIGEN-18 AS TRACERS, IN THE SAMALAYUCA DUNES NORTHERN MEXICO

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ABSTRACT

This paper presents the results of an initial study, using the stable isotopes of deuterium and oxygen of groundwater near the border area around Samalayuca Dunes and Juarez (Mexico) and Columbus (U.S.A.). We found that the groundwater around Columbus is isotopically different from the Samalayuca Dunes. Area and we observed that the isotopic enrichment at Juarez Valley is due mainly to a mixture between groundwater coming from the Samalayuca Dunes area and from the Juarez Valley aquifer.

RESUMEN

Este artículo presenta los resultados de un estudio inicial, utilizando los isótopos estables del hidrógeno y del oxígeno en el agua subterránea cercana a la zona fronteriza, alrededor de los Médanos de Samalayuca y Juárez (México), y Columbus (U.S.A.). Se encontró que el agua subterránea alrededor de Columbus es isotópicamente diferente a la de la zona de los Médanos de Samalayuca y se observa que el enriquecimiento isotópico en el Valle de Juárez es atribuible principalmente a una mezcla entre el agua subterránea que proviene de la zona de los Médanos de Samalayuca y del acuífero del Valle de Juárez.

INTRODUCTION

Thermoelectric plants in northern Mexico require large quantities of fresh water for cooling. The plant near Samalayuca, Chihuahua, uses groundwater and as the region is extremely arid (average precipitation less than 250 mm) groundwater is a valuable resource and recharge is slow. Thus it is necessary to understand the behavior and properties of the aquifers to avoid difficulties in the future, like in other parts of the country previously reported [1,2].

Previous geological studies [3] reported the possibility of the existence of two aquifers near Samalayuca Hill (Fig. 1). According to Rangel [3] one of the aquifers is confined and probably related to a major aquifer in the Columbus, N. M. area, and the other is a water table aquifer in the sand of the Samalayuca Dunes. Ariel Construcciones [4] suggested that groundwater flows out of the Samalayuca dunes to Juarez Valley.

In this study we have provided isotopic data to show the relations of water in the Samalayuca Dunes aquifer to groundwater in the other aquifers of the region.

GEOLOGICAL FEATURES

The study area is located physiographically in the Basin and Range Province [5] and it is characterized by a major anticlinorium with Mesozoic limestones and Jurassic quartzites forming elongated ranges with a NW-SE strike.

Farther west, igneous rocks are prevalent in the uplands but in the study area outcrops of igneus rocks occur only at the south and

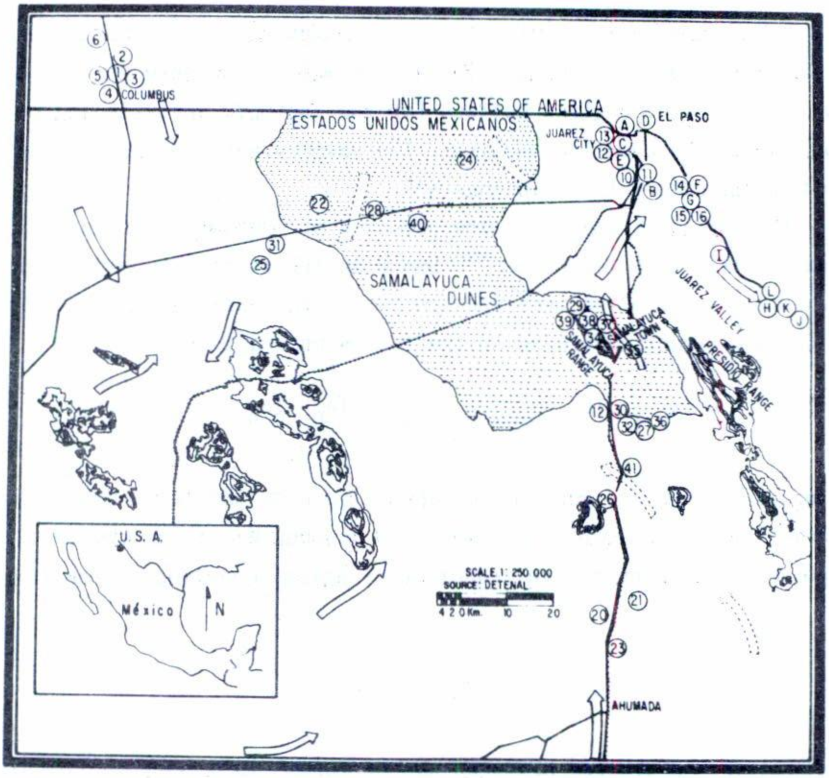

Fig. 1 Map of the study area showing sampling places and groundwater flowlines after Ariel (4), Rangel (3) and McLean (15).

north limits. The cretaceous limestones are excellent aquifers in some places.

Rangel (3) reports that the intermontane valleys are underlain by alluvium consisting mainly of clays and sand, up to 800 m thick, overlain by lacustrine deposits which include an evaporitic layer. Over much of the area the surface material is eolian sand, in dunes, up to 100 m thick.

Surface run off that reaches the valley during the brief, intense, storms of the rainy season, immediately infiltrates, thus there are no natural channels in the valley.

SAMPLING AND ANALYSIS

Water samples were collected from irrigation wells and springs of the Samalayuca Dunes, and from irrigation wells elsewhere in the region, using narrow-neck glass bottles for the isotopic analysis and poly ethylene flasks for chemical analysis. The samples were transported directly to the laboratory to begin analysis.

The Oxygen-18 analysis were prepared at IFUNAM, according to the Epstein and Mayeda technique (6) based in the isotopic analysis of CO_2, in a triple collector mass spectrometer, previously equilibrated with a sample aliquot according to the following reaction:

$$H_2{}^{18}O + C^{16}O_2 \rightleftharpoons H_2{}^{16}O + C^{18}O\ {}^{16}O.$$

Deuterium analysis where done in collaboration with the Water Resources Division of the U. S. Geological Survey at Reston, Va. using the zinc technique for the quantitative reduction of water according to the reaction:

$$H_2O + Zn \xrightarrow{450°C} H_2 + ZnO.$$

The analysis of the evolved hidrogen was performed in a double collector mass spectrometer.

Oxygen-18 and deuterium analysis are reported as usually (7) in per mil deviation (‰) from a standard sample called SMOW (Standard Mean Ocean Water) according to the definitions

$$\delta D = \left(\frac{R_x - R_s}{R_s}\right) 10^3 \quad \text{and} \quad \delta^{18}O = \left(\frac{R_x - R_s}{R_s}\right) 10^3,$$

where the R_x and R_s are the isotopic ratios of corresponding isotopes (D/H or $^{18}O/^{16}O$) in sample and standard respectively.

Major-ion chemical analysis were done according to the laboratory analysis methods described by Skougstad (8) in the chemical laboratory of Brigada Móvil de Perforación, C.F.E.

Isotopic data and results of major ion chemical analysis are shown in Table I.

DISCUSSION

To help the interpretation we plotted the isotopic data of this work and that of Payne and García [9] with the Craig's meteoric water line [10]. Using the combined data we could recognize three well-defined groups of groundwater as shown in Fig. 2.

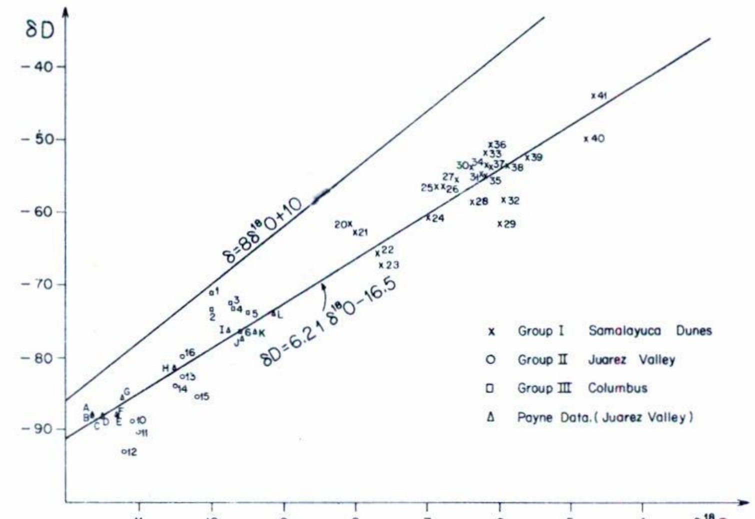

Fig. 2 ISOTOPE COMPOSITION OF GROUND WATER AT BORDER AREA
The lettered samples are from the work of Payne [a] and the numbered samples correspond to present work.

Group I (Samalayuca Dunes).- This groundwater fits geographycally with Samalayuca Dunes are and falls under the meteoric line suggesting that it has undergone evaporation in the processes of precipitation and infiltration [11]. Most precipitation events in this area originate in the Gulf of Mexico which have an isotopic distribution slightly above the meteoric line [12].

TABLE I

ISOTOPIC ANALYSIS (PER ml DEVIATION FROM SMOW) AND MAJOR ION CHEMICAL ANALYSIS (mEQUIVALENTS)

Sample	δD	$\delta^{18}O$	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^-	$CO_3^=$	$SO_4^=$	Cl^-	NO_3^-
1	-71.2	-10.0	0.12	0.16	13.61	0.12	5.98	0.05	6.96	1.45	0.00
2	-73.6	-10.0	0.53	0.24	10.43	0.12	5.59	0.10	5.18	1.38	0.01
3	-72.6	- 9.7	0.08	0.10	15.13	0.11	6.50	0.24	6.41	1.73	0.02
4	-73.2	- 9.7	1.45	0.46	14.09	0.17	6.10	0.06	7.64	2.47	0.00
5	-74.0	- 9.5	0.60	0.11	11.09	0.13	5.74	0.10	5.20	1.33	0.00
6	-76.5	- 9.6	0.11	0.10	16.39	0.05	4.91	0.20	8.60	2.32	0.00
10	-88.9	-11.1	4.10	0.95	2.44	0.08	3.08	0.00	2.56	1.93	0.00
11	-90.6	-11.1	3.75	0.78	2.24	0.08	2.73	0.00	1.92	2.22	0.00
12	-93.0	-11.2	2.25	0.67	2.08	0.07	2.58	0.02	0.85	1.65	0.00
13	-82.8	-10.4	4.50	1.84	15.83	0.09	4.37	0.00	10.83	7.05	0.00
14	-84.1	-10.5	7.00	2.09	12.26	0.11	3.23	0.00	10.89	8.61	0.00
15	-85.4	-10.2	5.80	0.92	12.48	0.10	4.48	0.00	9.45	6.20	0.00
16	-80.1	-10.4	4.35	0.66	9.91	0.10	3.98	0.00	5.24	6.58	0.00
20	-61.7	- 8.1	0.14	0.15	25.35	0.11	4.46	0.24	12.95	9.10	0.01
21	-62.7	- 8.1	1.80	0.97	24.40	0.15	4.09	0.00	14.01	9.75	0.00
22	-65.5	- 7.7	2.30	2.89	32.17	0.56	7.67	0.00	19.58	10.24	0.00
23	-67.2	- 7.7	1.00	0.23	14.67	0.12	4.64	0.02	7.47	4.90	0.02
24	-60.9	- 7.0	1.95	1.30	13.43	0.16	2.19	0.00	10.29	3.56	0.05
25	-56.5	- 6.9									
26	-56.6	- 6.8	1.90	0.45	12.91	0.04	3.62	0.07	9.04	3.02	0.00
27	-55.5	- 6.6	5.95	3.08	3.48	0.04	3.10	0.00	8.72	0.54	0.01
28	-58.5	- 6.4	0.50	0.10	11.48	0.10	5.58	0.28	6.64	1.18	0.02
29	-61.5	- 6.0	19.46	3.11	0.74	0.00	1.43	0.00	21.40	0.34	0.00
30	-53.8	- 6.4	6.00	3.31	4.65	0.03	2.64	0.00	10.50	0.70	0.00
31	-54.7	- 6.2	1.30	2.64	21.55	0.07	8.11	0.00	12.25	5.74	0.00
32	-58.3	- 5.9	2.10	0.10	1.01	0.04	1.10	0.00	2.16	0.24	0.00
33	-51.9	- 6.2	5.95	3.10	4.03	0.04	2.02	0.00	10.55	0.85	0.00
34	-53.5	- 6.2	2.75	1.28	0.98	0.04	2.16	0.00	2.67	0.25	0.00
35	-55.0	- 6.2	4.40	0.67	1.87	0.03	1.37	0.00	5.67	0.24	0.01
36	-51.0	- 6.1	9.90	2.85	2.90	0.12	3.07	0.00	12.76	0.44	0.02
37	-53.8	- 6.1	4.65	1.05	1.33	0.03	1.98	0.00	4.86	0.24	0.00
38	-53.6	- 5.9	8.85	1.80	0.98	0.04	1.94	0.00	10.19	0.34	0.00
39	-52.5	- 5.6	8.15	3.14	3.03	0.06	2.60	0.00	11.00	0.74	0.00
40	-49.8	- 4.8	0.70	0.11	8.22	0.09	3.93	0.13	5.32	0.74	0.00
41	-43.7	- 4.7	0.12	0.11	13.04	0.03	4.80	0.12	5.04	3.11	0.02

Group II (Juarez Valley).- This groundwater is found in the wells in Juarez Valley. The isotopic enrichment increases in the SE direction according to groundwater flow as was previously reported by Payne and García [9].

Group III (Columbus).- Groundwater from the Columbus area has an isotopic content different from that of the Samalayuca Dunes group.

In Samalayuca Dunes around Samalayuca Hill the samples 37, 38, 39 (springs), 33, 32, 29 (shallow water around 15 m depth) and 34, 28 (deep water around 160 m depth) show no correlation between isotopic enrichment and depth. Thus, here, there is no isotopic evidence of two aquifers, at least within the range of depths sampled.

According to water flow lines (Fig. 1), isotopic contents of samples 20, 21 and 23, probably show the influence of groundwaters coming from Villa Ahumada to the south of the study area. The isotopic content of sample 22, from the other side of the Samalayuca Dunes indicates the influence from the aquifer of group III (Columbus). The wide dispersion in the isotopic data from groundwater at Samalayuca Dunes can be explained by the fact that these waters reflect the extreme arid conditions of the area. The scant precipitation itself presents a wide isotopic dispersion, as can be seen from data from the station at the City of Chihuahua, about 250 km South of the studied area [13].

Group II waters, represent the stable isotopic composition of groundwater taken from irrigation wells in Juarez Valley. The points fall on a line and the previous report of Payne and García [9] classified it as an evaporative line because the increase in isotopic enrichment corresponded to an increase in salinity of the water and to the direction of the hydraulic gradient in the valley. The most enriched ($\delta^{18}O$) and saline waters were found farthest from the City of Juarez, then Payne and García [9] concluded that isotopic data indicated that the increase in salinity is due to evaporation and the gradual increase in isotopic enrichment southward down the valley suggest a re-cycling of the excess irrigation water, with the resultant increase in salinity. In this work, we found a strong correlation (0.97) among group I (Samalayuca

Dunes) and group II (Juarez Valley) to the line $\delta D=6.22\delta^{18}O+16.5$, as shown in Fig. 2.These facts and the groundwater flow lines [4] (see Fig. 1), all suggest that the isotopic enrichment observed in Juarez Valley is caused by a mixture of groundwater coming from Samalayuca Dunes and groundwater from the Juarez aquifer which is flowing in the NW-SE direction. We do not neglect the significance of the recycling process in the increase of salinity of the waters.

Chemically, waters of the area are mainly calcium-sulphate or sodium-sulphates types and we observed that, at the Samalayuca Hill area, there was a strong chemical dilution and undersaturation in calcite, dolomite, aragonite and gypsium as calculated from WATEQF [14], suggesting a significant infiltration of meteoric waters through the permeable surface of this part of the sand dunes.

As a preliminary conclusion we believethat the Columbus aquifer belongs to a different hydrogeological system with little relation to Samalayuca Dunes aquifer. The groundwater in the Samalayuca Dunes is flowing northward to Juarez Valley, as in a normal free aquifer which perhaps receives important recharge from precipitation around the area of Samalayuca Hill.

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