ISOTOPIC AND CHEMICAL STUDIES OF GROUNDWATER IN THE LLANURA TUCUMANA GEOTHERMAL AREA; TUCUMAN, ARGENTINA

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INTRODUCTION

The Llanura Tucumana extends along the eastern Andean margin, between 27ºS-28ºS and 64º50'W-65º40'W. It is a structural depression infilled by a thick sedimentary sequence, as shown by the preliminary geophysical studies (Pomposiello, *et al.*, 1991, 2000; Favetto *et al*. 2000). It is bounded to the west by the Nevados del Aconquija (5500m) and the Sierra de Guasayán (600m) at east. Both ranges are part of the Sierras Pampeanas System. The southern part of this plain is an important thermal area, which is known through surface manifestations and drilled wells. There are a great quantity of artesian wells with discharge water at temperatures that oscillate between 30ºC and 50ºC.

The Aconquija System is a climatic barrier for the humid east winds. The precipitation is torrential with intense and short time storms, mainly in summer. The rain amount decreases gradually to the SE, from 1200 to 800mm and it is 600mm near the Río Hondo Dam area. The mean January temperature is 26.7ºC and the coldest month is July with 12.9ºC.

This paper presents the isotopic and chemical results and a first approach for the origin and circulation pattern of water.

GEOLOGY

The stratigraphic knowledge of the Tucumán basin is limited to the outcropping units and also through the drilled wells that penetrated the Quaternary alluvial sequences and the upper Tertiary. The crystalline basement is exposed at the west border of the basin and is formed by granitoids and layered schists assigned to Precambrian and Paleozoic. Also, the upper part of a Neogene redbed sequence crops out. According to gra vimetric and magnetotelluric results, more than 3000m of sedimentary deposits fill this basin (Pomposiello, *et al*., 1991, 2000; Favetto *et al*., 2000).

At the Sierra de Guasayán and Aconquija System the Tertiary sediments lie in discordance over the basement rocks. Within this sequence, Battaglia (1982) recognized several stratigraphic units. These are the Guasayán and Las Cañas Formation. The former reaches a thickness of 400m and consists of red and green siltstones with interbedded gypsum, deposits of tuffs, oolitic limestones. It is also characterized by pelites interbedded with volcanic materials and sand, marly deposits and a great quantity of gypsum . It was assigned to Miocene age (Battaglia, 1982). Unconformably, this unit is overlying the Las Cañas Formation, a sequence of red to brownish-red clay siltstones interbedded with sandstones and microconglomerates. Its outcrop thickness is only 20m and was assigned to Pliocene (Battaglia, 1982). The permeable thermal aquifers are within this Pliocene unit.

The Tertiary sequence on the eastern border of the Aconquija System differs in several ways from its counterpart in the Sierra de Guasayán. The lower portion is formed by red sandstones (50m) that grade upwards into greenish grey marls of saline lacustrine environment, belonging to the Río Salí Formation, which is attributed to Miocene. (Tineo, 2000). The upper part of the sequence consists of a conglomerate containing pebbles of volcanic rocks. The exposed section is less than 150m thick. No precise relationship has been found between the sequences on opposite sides of the basin.

The quaternary sediments are characterized by loessic and silt-loessic deposits considered to be of Pleistocene age (Sayago *et al*. 1987) and their thickness exceed 400m in some sectors (Vergara *et al.* 1990). In addition, there are Holocene alluvial fans,

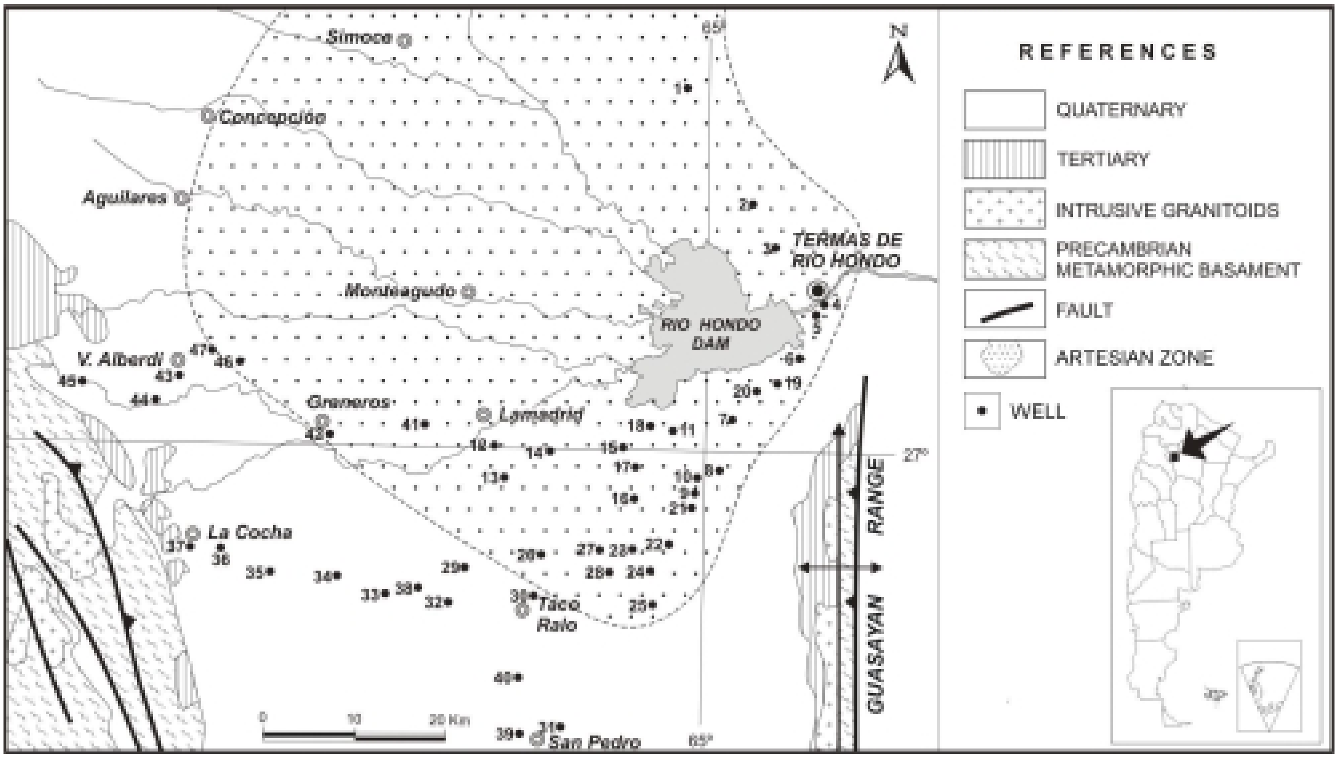

Figure 1: Geological map showing the well location

eolic, playa and recent deposits on the eastern Aconquija piedmont (Battaglia, 1982). Both sequences, Tertiary and Quaternary are very heterogeneous.

HYDROGEOLOGY

The Miocene aquifers (Guasayán Formation) are composed of green clays containing gypsum and halite. This results in water of poor quality, due to the sulphate, chlorine and magnesium compounds over a large zone. On the other hand, the Pliocene aquifers (Las Cañas Formation), generally have much higher water quality although still slightly saline. Water temperatures between 30ºC and 50ºC are observed in the Pliocene geothermal aquifer. The Pleistocene deposits (silt-loessic sediments) host aquifers which have water of good quality and thickness between 200 and 400m. Overlaying these sediments, the Holocene sequence bears aquifers with high rate of discharge and excellent qualities for most requirements. This Holocene accumulation, starting on the eastern slope of the Aconquija System with thickness up to 200m, decreases towards the east and the coarse materials entirely disappears at longitude 65° 22' W (Tineo, 2000).

MATERIALS AND METHODS

The chemical composition of the groundwater was studied in 47 boreholes located inside and outside of the artesian area, during June of 2000, in order to determine the characteristics of groundwater. Figure 1 presents the location of the sampled wells.

Isotopic analyses were done at INGEIS Laboratories. ^{2}H in water samples was measured by Coleman *et al*. (1982) procedure and for the measurement of ^{18}O was used the methodology described in Panarello and Parica (1984). Isotope ratios were measured with a multicollector McKinney type mass spectrometer, Finnigan MAT Delta S.

The results are expressed like δ, defined as:

$$\delta = 1000 \frac{R_S - R_P}{R_P} ‰$$

δ: isotopic deviation in ‰
S: sample
P: international standard
R: isotopic ratio ($^{2}H/^{1}H$, $^{18}O/^{16}O$).

The standard is Vienna Standard Mean Ocean Water (V-SMOW) (Gonfiantini, 1978).

The analytical errors were ±0.1‰ and ±1.0‰ for $\delta^{18}O$ and $\delta^{2}H$ respectively.

RESULTS AND DISCUSSION

Major elements chemical composition are presented in a Piper diagram form (Fig.2).

Table 1 shows the isotopic values $\delta^{18}O$, $\delta^{2}H$, the deuterium excess "d", defined as $d=\delta^{2}H-8\delta^{18}O$ (Craig, 1961), conductivity, water temperature and surging characteristics of the analyzed samples.

In addition, figure 3 exhibits a scatter plot $\delta^{18}O$-$\delta^{2}H$ of the water samples and a meteoric water line (MWL), $\delta^{2}H = 8\,\delta^{18}O+14‰$, estimated from Miró and Gonfiantini (1980) and Iglesias *et al.*(1990) for this area.

Like it was observed by Jurío *et al.*(1975) and in further publications, it results very difficult to correlate the different aquifer levels of a well with others neighbor one. This is a consequence of the fact that aquifers are located in sandy lenses presenting variable thickness and scarce lateral development. These characteristics are proper of the Pliocene and also Quaternary units. The same conclusion is reached through this isotopic study.

As is shown in the Piper diagram (fig.2), the majority of waters are sulfate-chloride-sodium type.

The lack of correlation between the isotopic composition and chloride and sulfate ions indicates that the salinization mechanism is mainly the leaching of old marine sediments. As it was noticed by Fontes and Molinari (1975), Miró and Gonfiantini (1980),

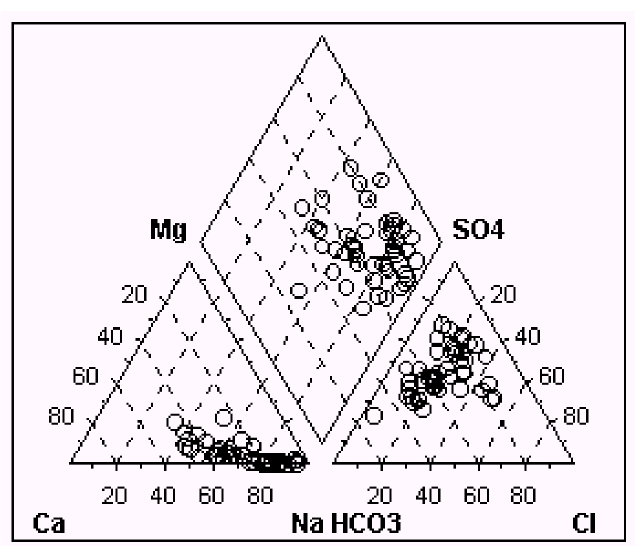

Figure 2: Piper diagram for the samples

Lab#	N#	$\delta^{18}O$ ‰	$\delta^{2}H$ ‰	d ‰	λ μScm^{-1}	T ºC	Well type
10938	1	-4.6	-26	11	983	27.9	Artesian
10939	2	-6.3	-39	11	880	40.7	Artesian
10940	3	-6.1	-35	14	878	30.5	Artesian
10941	4	-6.2	-35	15	544	42.2	Artesian
10942	5	-5.7	-36	10	805	41.7	Artesian
10943	6	-5.6	-38	7	708	36.2	Artesian
10944	7	-5.9	-35	12	1055	44.3	Artesian
10945	8	-5.9	-40	7	902	42.4	Artesian
10946	9	-6.0	-39	9	1324	39.6	Artesian
10947	10	-6.0	-35	13	800	35.1	Artesian
10948	11	-5.9	-31	16	656	33.5	Artesian
10949	12	-5.1	-31	10	618	37.2	Artesian
10950	13	-5.2	-29	13	629	37.3	Artesian
10951	14	-5.5	-33	11	710	36.2	Artesian
10952	15	-5.8	-34	12	741	34.5	Artesian
10953	16	-5.9	-33	14	606	41.1	Artesian
10954	17	-6.1	-33	16	495	41.5	Artesian
10955	18	-6.3	-37	13	1228	33	Artesian
10956	19	-6.8	-35	19	828	36.8	Artesian
10957	20	-6.4	-33	18	428	32.7	Artesian
10958	21	-7.0	-41	15	920	36.2	Artesian
10959	22	-6.3	-42	8	1114	40.8	Artesian
10960	23	-7.0	-40	16	1168	42.3	Artesian
10961	24	-6.3	-40	10	1307	381	Artesian
10962	25	-6.6	-39	14	1566	42.6	Artesian
10963	26	-7.0	-39	17	809	44.1	Artesian
10964	27	-6.5	-38	14	859	47.1	Pump
10965	28	-6.1	-37	12	1005	50.2	Pump
10966	29	-6.0	-34	14	751	22.4	Pump
10967	30	-6.2	-36	14	699	38.5	Pump
10968	31	-7.2	-46	12	2090	39.8	Pump
10969	32	-6.1	-35	14	864	23.2	Pump
10970	33	-6.0	-32	16	540	23.9	Pump
10971	34	-6.0	-35	13	2310	18.5	Pump
10972	35	-5.9	-31	16	625	26.6	Pump
10973	36	-5.7	-29	17	871	22.7	Pump
10974	37	-5.3	-29	13	1173	23.9	Pump
10975	38	-6.1	-37	12	584	25.9	Pump
10976	39	-6.2	-35	15	514	15.6	Pump
10977	40	-6.4	-44	7	1066	27.3	Pump
10978	41	-5.8	-31	15	772	29.6	Pump
10979	42	-5.3	-26	16	366	26.8	Pump
10980	43	-4.7	-23	15	1598	19.7	Pump
10981	44	-4.9	-24	15	1410	24.1	Pump
10982	45	-5.1	-25	16	1049	21	Pump
10983	46	-5.2	-28	14	586	38.5	Pump
10984	47	-5.3	-29	13	707	23	Pump

Table 1: Isotopic data, conductivity and well type

despite the high elevation of the Nevados del Aconquija (5500m) an altitude effect is not observed. As a consequence, the absence of these differences in isotopic composition complicate the possibility of water isotope typifycate.

The only possible water correlation are made near the recharge zone (Marapa river, samples 43,44 y 45) and a defined, more isotopically depleted region at the SE of the basin. The probable causes are the existence of a zone of older waters, recharged in a colder period or to an allochthonous recharge or a local recharge depleted by amount effect Tritium and ^{14}C analyses are needed to prove these hypothesis.

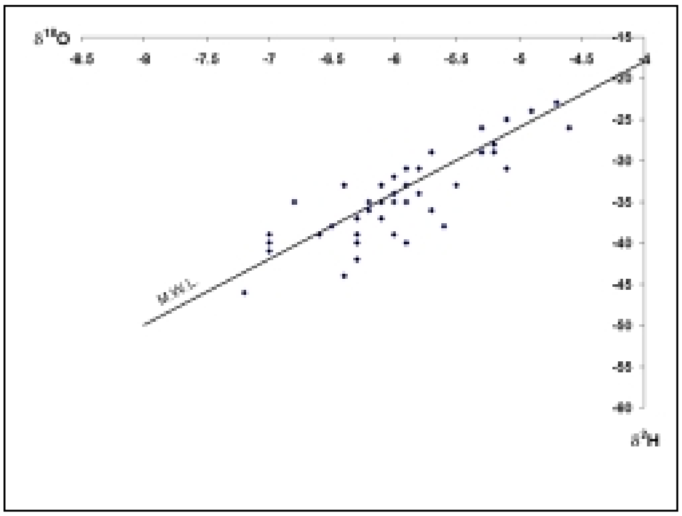

Figure 3: $\delta^{18}O$-$\delta^{2}H$ scatter plot

CONCLUSIONS

The Llanura Tucumana geothermal area has been studied by means of the hydrochemistry and Isotope Hydrology.

As established in previous papers, the system is heterogeneous and it was not possible to find out a systematic pattern that allows water typifying.

^{3}H and ^{14}C studies are imperative in order to clarify paths and movements of groundwater into the aquifer units.

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