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ISOTOPIC AND CHEMICAL STUDY OF THE WATER RESOURCES IN THE IQUIQUE PROVINCE

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1.- AIMS

The Pampa del Tamarugal study area is located in the Northern part of Chile, and constitutes a part of the Atacama Desert. Groundwaters are the principal water resources in the area, for human comsumption and agriculture activities, being the only water supply for the city of Iquique. The water quality ranges from freshwater on the eastern side of the Pampa, at the margin of the Andes, to saline water westward in the Salares Pintados and Bellavista, where the groundwater level is close to the earth surface.

The aim of this geochemical and isotopic study was to contribute to a better understanding of the principal processes which govern the water cycle in the area. Information about recharge areas of groundwaters, their age, their flow system, etc., is very important for a better management of these water resources.

2.- MATERIALS AND METHODS

In different phases of the hydrological cycle, water was collected for isotope and chemical analyses as follows:

Precipitation: A network of rain stations located at different altitudes was used to collect individual rainstorms (Fig. 1).

Springs: First, most of the high and low altitude springs were sampled, but later during the research, 12 springs were chosen for a continuous sampling (Figure 4).

Rivers: Base flow samples were collected at different points along the rivers (Figure 9) in three of the main basins: Tarapacá, Aroma and Chacarilla. Flood waters were also collected during 1985 rainy season (January - March) at two localities: Pachica on Tarapacá river and Ariquilda on Aroma river.

Groundwaters: 46 wells located at different points of the Pampa basin were sampled, in most cases after pumping. The identification and location of these wells can be seen in figure 14.

Sampling of springs, rivers and well waters was done in three different times, in 11-12/83, 5/84 and 12/84. Temperature, pH, electrical conductivity and alcalinity were determined in field.

Chemical analyses were carried out in the DGA Chemical Laboratory and isotope measurements (^{18}O, ^{2}H, ^{13}C, ^{14}C) in the Environmental Isotope Laboratory of the Comisión Chilena de Energía Nuclear. Tritium was analyzed at the IAEA laboratory in Vienna. Oxygen isotope ratio was measured as CO_2 gas equilibrated with the water sample at 25° C; deuterium was measured after reducing the sample in hot uranium, and carbon-13 as CO_2 produced by an acid reaction with 95% phosphoric acid. The mass spectrometer used was a Micromass 602 C. The ^{18}O and ^{2}H ratios are reported respect to SMOW (Standard Mean Ocean Water, Craig, 1961)

and the ^{13}C ratio respect to PDB. The deviation of the isotope ratio from the standard is given in δ o/oo units;

$$\delta\ [o/oo] = \left(\frac{R\ sample}{R\ standard} - 1 \right) x\ 1000$$

where R is the $^{18}O/^{16}O$, $^{2}H/^{1}H$ or $^{13}C/^{12}C$ ratio. Analytical reproducibilities of results are 0.2°/oo for ^{18}O, 2°/oo for ^{2}H and 0.2°/oo for ^{13}C.

With respect to the radioactive isotopes, tritium was measured in a gas counter, after enrichment, with an error of ± 0.2 TU. The data are reported in TU, where TU = T/H x 10^{-18}, T and H are atomic concentration of tritium and hydrogen respectively. For ^{14}C analyses, benzene was synthesized and counted in a Packard Tricarb liquid scintillator counter. The results are expressed as percent modern carbon (pmc) with respect to 0.95 activity of the NBS oxalic acid. The analytical uncertainty of this method is about 1 pmc.

For chemical analyses, the following standard methods were used: for carbonate and bicarbonate determination, titration with sulphuric acid 0.01 N; for chloride , titration with mercury nitrate 0.01 N; for calcium and magnesium, titration with EDTA.

Turbidity methods for sulphate and colorimetric methods for silica determination were used. Sodium and potassium were determined by flame-photospectrometry.

3.- RESULTS

The river water data show some chemical and isotopic differences in the three sampling seasons, whereas the springs and wells show very small variations.

Therefore, the data presented in the tables below represent the mean value of the laboratory measurements (chemical and isotopic data) and the field results of one specific sampling date. When it was possible, the results of samples taken after pumping were used. Table 1 shows the geochemical and isotopic data of river and spring samples, and Table 2, of well samples.

The error of charge balance determinations (total cations - total anions)/ (total cations + total anions) was usually less than 2°/o (Tables 3, 4). Some element ratios (meq/meq) and the deuterium excess "d", defined as $d = \delta^{2}H - 8\ \delta^{18}O$, for various water samples are also given in Tables 3 and 4.

The chemical data and some element ratios for the flood waters of 1985 are given in Tables 5,6. Isotope analyses of these waters are being processed.

In the following, the geochemical and isotopic data are discussed in order to delineate genetic relations and to identify some of the processes which could explain the water composition (Magaritz et al, 1981).

3.1 Precipitation Data

The stable isotope weighted mean values of summer (12/83 - 3/84) and winter (4-6/84) rains at the sampled stations are plotted in Figure 2. Most of these values are located close to the global meteoric water line (Craig, 1961). The "d" parameter seems to be slightly higher than world values. Similar weighted mean values were found by Fritz et al, 1981. Summer rains show very large variations in stable isotope content, whereas winter values move within a smaller range.

A correlation between $\delta^{18}O$ values and altitude is clearly found for summer rain (Fig. 3) excepting one station located in the extreme North of the study area (Pumire),which does not fit this trend. It is necessary to mention that the Pumire value is a mean of only very few samples. Nevertheless, this behaviour may indicate that the isotope composition of this rain is controlled by processes which are different from those at the other stations.

The isotope gradient for summer rains is about 1°/oo/100 m, which is significantly larger than values reported in others places (0.15 - 0.5°/oo, Gat, 1980). Thus, the isotope gradient seems not to be directly related to the so called "altitude effect".

A meteorological study recently carried out for this area (Fuenzalida and Rutland, 1985) shows that the rain in the Altiplano is related to air masses coming from the East. Isotopic data of this study suggest that these air masses should move at high altitudes and do not participate in the rain and evaporation processes, which occur in the Amazon basin as reported by Salati and Marques, 1984. As soon as these air masses arrive to the Altiplano, they are involved in the formation of high cumulus nimbus clouds, near the high volcanic peaks of the region. The first rains of a storm event (we refer to a storm event as to a set of afternoon rains originating from the same air mass) are always enriched in ^{18}O and ^{2}H. As the storm evolves , rains become more depleted in heavy isotopes,probably as a result of rain out of the air masses. Thus, the mean weighted values for the high elevation stations (with higher precipitation amounts), reflect the depleted rain of later evolution stages of the air masses. On the Western slope of the Andes, where only the edge of the storm affects, isotope data seem to reflect only the early stages of the storm evolution (heavier values). Pacific air climbing the Andes from the West possibly has no influence because of the dryness of these air masses. The presented model could explain the high isotopic gradient with elevation.

The analysis of the meteorological information concerning the winter

3.2 Springs

Stable isotope data.-

A very large variation in the oxygen and hydrogen isotopic composition of spring waters is observed (Fig. 5), but the most outstanding characteristic is that non of themis located on the local meteoric water line. The "d" parame ter ranges from 7.4, on the high altitude springs, to -7.4 in the Chacarilla spring, indicatinga high degree of evaporation (Table 3).

Isotope content of the high elevation springs (3600 m to 4100 m) ranges from - 14°/oo to -12°/oo in ^{18}O and -106°/oo to -96°/oo in ^{2}H. However, these waters are enriched in ^{18}O and ^{2}H compared to the present rains at their recharge al titude.Miraflores spring water (1420 m.a.s.l.) in the Pica area, has an isotopic composition similar to the one of high altitude springs, suggesting similar rechar ge areas (Table 1). However, in this area also some springs enriched in heavy so-topes are found, like Puquio Núñez.

A second group of springs at lower altitudes (1400-3350 m.a.s.l.) shows an enrichment in both isotopes, but similar "d" values (Fig. 5).

Concerning ^{14}C, the data presented in Table 1 include values reported by Fritz et al (1981), and data obtained during this study. The values range from 106 pmc to about 10 pmc, indicating differences in residence time for these waters. Two of the high altitude springs (Cono and Chituma) have also a measurable tritium concentration. These two springs and Chicura, with 99 and 106 pmc, are very recent waters (younger than 30 years). Sagasca spring, with 85 pmc, also indicates young water . The difference in stable isotope data between this spring and those discu ssed above (Sagasca is enriched in heavy isotopes) is due to the lower mean alti-tude of its recharge area. The two other springs in that region, La Calera and Ma caya, look older (47 pmc and 10 pmc respectively). The difference in stable isoto pe content between Sagasca, La Calera and Macaya springs, could be associated to altitude differences of the recharge areas or to the existence of lighter rains in

storm event of 1984 (Fuenzalida and Rutland, 1985), showed that this event was originated by air masses coming from the North (Caribbean region), moving along the Pacific coast without any influence of the higher Andes. Along their trajectory, they mix with maritime air, process which may explain the almost homogeneous isotope content of winter rains.

older times. Other springs like Potrero, Puquio Núñez and Miraflores, show intermediate ages, with about 40 pmc.

Chemistry.-

Large variations in chemistry are observed in spring waters, reflecting their interaction with rocks. Since the soil cover of recharge areas is very shallow or does not exist, the main process of interaction takes place between the water and the volcanic rocks. Fig. 6 B shows a general positive correlation between Na^+/Cl^- ratio (meq/meq) and total salt content (expressed as EC). As in general rains are characterized by Na^+/Cl^- ratios close to 1, values above 2 reflect that most of the salt content is coming from the rocks and is not a result of concentration by evaporation of rain waters.

No correlation is observed between ^{14}C content (ages) and salt content or Na^+/Cl^- ratios (Tables 1, 3). The two most recent springs Chichura and Chituma show quite different Na^+/Cl^- ratios (2.00 and 2.75 respectively).

The relation between major anions $SO_4^=$ and Cl^- in the spring waters is shown in figure 7 B. In general, all springs, except the ones from Pica area (P. Núñez, P. Miraflores) and Chacarilla show high $SO_4^=/Cl^-$ ratios, up to seven. Based on T and ^{14}C data, young springs have higher $SO_4^=/Cl^-$ ratios than older ones. This change suggests that oxidation of sulfide, the main source of $SO_4^=$ in volcanic rocks, ocurres at early stages of interaction. As water interacts longer with the rocks, this process stops, probably due to lack of O_2, and only a leaching of Cl^- continues. Thus, in spring waters with longer residence times, the $SO_4^=/Cl^-$ ratio decreases below 1.

Another chemical parameter, which seems to reflect the rock-water interaction time, is the Na^+/K^+ ratio (Fig. 8). Its variation might reflect alteration of plagioclase mineral in contact with the waters, and formation of clay minerals or/and K-feldspar. This can be seen in figure 8, that shows increasing Na^+/K^+ ratios for decreasing ^{14}C - content in spring waters.

In conclusion, chemical composition of springs reflects the different pathways and interaction times between waters and rocks. No correlation exists between "age" of the water (^{14}C-content) and the total salt content, but element ratios show a very good correlation with "age", giving an indication of the extend and the time involved in water-rocks interactions.

Stable isotope ratios for springs show deviation from the rain values, suggesting that isotope content changes, already in the recharge areas, along evaporation lines with a slope close to 7. This behaviour can be related to the processes of sublimation and melting of snow and even evaporation in the unsaturated zone. The large isotope range of these waters can be associated both with differences in the recharge areas and/or with past shifts in isotope content of rains.

3.3 Rivers

Isotope Data.-

All river waters analyzed have tritium above analytical error, indicating recent origin. The average value in river waters is slightly below 2 TU, which is lower than the ones expected for rain (~ 10.0 TU). Most probably, this reflects a mixing of recent rain and water with no tritium. The highest T-values are observed in the Pachica area; this can be explained by an exchange between the atmosphera and the water involved in agricultural activities. ^{14}C activity of 110 pmc and ^{13}C-content of -11.8 °/oo are also a result of exchange and influence of irrigation water.

Stable isotope compositions of river waters show a pattern similar to the one of springs (Fig. 5). The high altiplano Collacagua river is depleted in ^{18}O and ^{2}H compared to the Aroma river, even taken into account evaporation, thus reflecting the difference in catchment areas. Isotope data of samples taken along the flow direction clearly show evidence of evaporation (Fig. 10) in Aroma and Chacarilla rivers. For the Tarapacá river, even if there is a shift in stable isotope content to heavier values, the data sit on a line with a slope close to 8, apparently not showing any evaporation.

Chemistry.-

In all basins, river waters show a salinity increase in flow direction. For Aroma, Coscaya and Chacarilla rivers, this could be caused by evaporation, as is also shown by stable isotope data. Na^{+}/Cl^{-} ratios show lower values with increasing salinity (Fig. 6 A), telling about addition of salt from river beds. For the Tarapacá river, the element ratio changes only slightly with increasing salinity, which could indicate evaporation. Nevertheless, stable isotope data do not show

this process, unless evaporation occurred in equilibrium conditions. Another way to explain these data could be associated to contributions to the base flow from groundwaters originated at lower elevationsthan Sibaya.

It is interesting to note that Na^+/Cl^- ratios in spring and river waters of the same basin are not similar, suggesting that the analyzed springs do not significantly contribute to river waters.

Similar to high altitude springs, rivers show high $SO_4^=/Cl^-$ ratio, (Fig. 7 A) reflecting sulfide oxidation in the volcanic rocks. Na^+/K^+ ratios of these waters show values between 10 and 17,values which reveal a short interaction time with volcanic rocks, as was earlier mentioned for young springs.

In conclusion, river waters are mainly recent and chemistry is in general similar to the one of young springs. But river waters and spring waters of the same basin show quite different Na^+/Cl^- ratios. Salinity increase is related to salt leaching from river beds, but also to evaporation which takes place along the rivers' courses.

3.4 Flood waters.-

Two of the principal rivers, Aroma and Tarapacá, were sampled continuously during the summer 1985. Two samples were collected daily, and the frequency increased to one sample per hour during floods. The chemical data and some element ratios are presented in tables 5 and 6.

In general, these data do not show large chemical variations as salinity decreases, which indicates that the flood waters' path way through the rocks is similar to the base flows' path way . Furthermore, this suggests that spring waters, which show long interaction times with the volcanic rocks, might have only a minor contribution to the river waters.

3.4.1 Tarapacá at Pachica

During the sampling period, only two relatively important floods ocurred. Unfortunately, the flow rate was not measured because of mechanical problems in the gauge station. At the sampling point, the average salinity measured for the base flow was about 1900 μmhos. During the floods, salinity values decreased to 850 umhos at the peak, whereas the flow rate increased at least by a factor of 10. During the recession of the flood, salinity tended to increase, again. The fact that the salinity decreased only by a factor of 2, means that large quantities of salt were drained from the basin during the flood. Since the salt contribution from the rain is not important, the principal source had to be the soil layer and the surface of the volcanic terrains.

In general, element ratios of flood waters show some variations, but not large ones compared to the spring and base flow waters in the area (Table 3). The Na^+/Cl^- ratios change to higher values with a decreaseing salinity (Fig. 10), which might suggest that, compared to the base flow, floods release salts with higher Na^+/Cl^- ratios. A similar trend is observed for $SO_4^=/Cl^-$ ratios (Fig. 6 B),

ting long residence times (see spring discussion), in agreement with ^{14}C data.

The rest of the groundwaters show low Na^+/Cl^- ratios, probably indicating loss of Na^+ through cation exchange for the Central zone and mixing with saline water (with low Na^+/Cl^- ratio) for the Western zone. The Eastern zone is also characterized by higher $SO_4^= /Cl^-$ ratios, resembling spring and river waters (Fig. 21 A). The other zones shows lower ratios. This reflects a more intensive interaction with the rocks.

Waters of the Central zone are less than 5000 years old. If one assumes the possibility of C^{14} dilution due to interaction with carbonate rocks, they may be even younger. On the other hand, groundwaters at least 5000 years older are found in the Western zone and in the Eastern zone (Canchones area).

This ^{14}C distribution cannot be explained only by a flow system with recharge from rivers and later flow through the sedimentary filling of the Pampa. There must be other complex processes like flow through rocks and faults, to explain these data.

3.5.3 Pica Region (Region 3)

Two groups of waters can be distinguished in this area. The more depleted one, located around Pica, could have its recharge area in the high Altiplano, as stable isotope content of the springs in this area do suggest. The ^{14}C content of this aquifer varies between 25 and 30 pmc.

The second group of waters (Esmeralda-Matilla), appears more enriched in ^{18}O and ^{2}H, and younger (^{14}C values of 80 to 106 pmc), and is probably related to the Western fault line (Fig. 15, Tables 1, 2).

^{14}C content seems to be correlated with the $\delta^{18}O$ values of these waters

but the opposite one for Na^+/K^+ ratios (Fig. 6 A).

These chemical trends reveal processes that occur during the water-surface rock interaction, which are slightly different from the base flow processes.

They reflect a short interaction time, during which Na^+ and K^+ leach together from rocks, and $SO_4^=$ is released in large quantities compared to Cl^-. The older waters (base flow) have longer evolution times, which cause loss of K^+ respect to Na^+ and increase of Cl^- respect to $SO_4^=$ and Na^+. The same trend, but accentuated, is shown by spring water data, where older waters have higher Na^+/K^+ and lower $SO_4^=/Cl^-$ ratios, as was already discussed.

3.4.2 Aroma at Ariquilda

Base flow and flood waters of the Aroma river are much more saline than Tarapacá river waters. Na^+ and Cl^- are the dominant iones instead of Na^+ and $SO_4^=$ of Tarapacá waters. For $SO_4^=/Cl^-$, Na^+/Cl^- and Na^+/K^+ ratios, the trends observed for Ariquilda flood waters are very similar to those of Tarapacá flood waters (Fig. 12 A, 12 B, 13 A, 13 B).

In conclusion, the chemical evolution of river waters reflects the type of reaction taking place in their basins. Large salt quantities carried by floods indicate an important sub-surface flow contribution. Furthermore, in the Aroma river, salt contribution due to dissolution of evaporites from the river bed is also important.

3.5 Groundwaters

In general, chemistry data show a salinity increase toward the south-west part of the Pampa, related to a) dissolution of evaporite mineral found in the sedimentary sequence; and b) evaporation from Salares, where the water level is close to the surface.

As spring waters, groundwaters too show a wide range in stable isotope content, that could be related to different recharge areas. In a δ^2H vs $\delta^{18}O$ plot (Fig. 15), most of the not strongly evaporated groundwaters are located on a line with a slope of 8 and a "d" parameter of 0°/oo . This "d" value is significantly different from the "d" value of rains (d= 13°/oo, Fig. 2) and spring waters (d = 5°/oo, Fig. 10).

Based on the data and for a better discussion, the Pampa area was divided into four regions: Northern (Aroma), Central (Tarapacá), Pica and Southern region (Salar Pintados).

3.5.1 Northern Region (Region 1)

Groundwaters of this region are the most enriched in ^{18}O and ^{2}H of the whole study area (Fig. 15). This could be related to the isotopic composition of rains in the probable recharge area, which, from the few data available, look like the most enriched in heavy isotopes (Pumire,Fig. 2 and 3). On the basis of chemistry and stable isotope content, this region clearly shows two types of waters of different origin (Fig. 16 A, 17 A, 17 B). The Northern waters, apparently not connected to the Aroma river, clearly show dissolution of halites on their pathway (Na^+/Cl^- ratios decreasing toward 1). Southern waters, more saline and depleted in ^{18}O, might be generated in the Aroma basin, but probably at lower mean altitudes than the river water. Na^+/Cl^- ratios below 1 indicate that, beside probable halite

dissolution, other water-rock interaction processes, like ion exchange, are important.

3.5.2 Central Region (Region 2)

Isotope data.-

A large spread in isotope content is observed in this area (Fig. 18 A), but based on location, isotopic and chemical information, it is possible to recognize three groups of waters. The Eastern one, including Canchones (the major water supply station for the region), is relatively enriched in ^{18}O and ^{2}H and its isotope composition is similar to the one of springs in the volcanic terrain to the east (Sagasca and La Calera). The Central zone, more depleted in heavy isotopes, is in general slightly enriched with respect to Tarapacá River. The Western zone, which includes the wells close to the Panamerican highway, shows a displacement below the line on which most of the groundwaters in the region are located. This indicates evaporation affecting waters of an isotopic composition similar to the one of the Central zone (Fig. 15, 18 A). Regarding the ^{14}C content of these waters (Fig. 18 B), the older ones are found in the Canchones area and at the Western margin (15 to 30 pmc) whereas the Central zone waters have ^{14}C values of about 60 pmc. ^{14}C data show a negative correlation with $\delta^{18}O$ values (Fig. 18 B). Lighter waters (Central zone) seem to be the youngest waters.

Chemical data.-

It was the analysis of these data that justified the division of Central Region groundwaters into three zones. In Fig. 19, Eastern and Central zone waters have lower Cl^- content than the evapored ones in the West. In figures 20 B and 21, element ratios are plotted versus ^{18}O content. The plots include springs of the Sagasca area and Tarapacá river. The high Na^+/Cl^- ratios of Eastern zone waters (DGA 131, 170, 171) are very similar to the ratios of the adjacent springs, sugges

(Fig. 22). If a common recharge in Altos de Pica is assumed, this indicates a change in isotopic composition of recharged waters with time. But data can be explained by different recharge areas for Pica and Esmeralda waters, too.

Chemistry.-

Esmeralda-Matilla waters are enriched in Cl^- with respect to Pica springs and wells, and Na^+/Cl^- ratios tend to decrease as salinity increases (Fig. 23 A, 23 B, Tables 1, 2). This suggestsless intensive interaction with volcanic rocks for Pica waters although they are much older than Esmeralda-Matilla waters.

An example of short interaction with the volcanic rocks might be the Collacagua river, with its higher Na^+/Cl^- ratio. Other element ratios show low values for $SO_4^=/Cl^-$ and variable Na^+/K^+, changing also with the $\delta\,^{18}O$ values (Fig. 24 A and B).

3.5.4 Southern Region (Region 4)

Based on salinity, two different types of waters are found in this region. The very saline ones are in the salar terminal area.

Isotope Data:-

Only few water samples like Pique Pintados and DGA 253 do not show clear isotopic evidence of evaporation (Fig. 25). The rest of the waters, including the less saline ones,are located on an evaporation line of a slope of 3 (Fig. 15). Three ^{14}C determinations of groundwaters of this region exist (Table 2). One of them, Pique Pintados, is relatively young (47 pmc), and appears very similar to the Central zone in region 2. The other two(corresponding to DGA 262 and Pozo Cerro Gordo) show very old waters, with a ^{14}C content of less than 5 pmc and 12 pmc.

Chemistry.-

Na^+/Cl^- ratios show large variations, even some values above 2.5 (Fig. 26 A). Dissolution of evaporites in the salar area changes these ratios to values close to 1. $SO_4^=/Cl^-$ ratios show a similar decreasing trend toward the salar, due to removal of sulfate as gypsum (Fig. 26 B). Na^+/K^+ ratios show large variations too (Fig.27), from 8 to 25, similar to those in region 2. High Na^+/K^+ ratios suggest water interacting extensively with volcanic rocks.

3.6 Aquifer Temperature

The data presented in Table 2 suggest the existence of a geothermal anomaly (Fig. 28). Wells where the water level is 20 or more meters deep have temperature values of 27 to 28° C. Even higher temperatures are found in the Pica region. Beside this, one of the wells (DGA 77a) sampled at two different depths has a temperature difference of 4° C in 25 m.

The anomalous temperature gradient in the study area suggests the existence of some sources of warm waters. However, data are not sufficient to support this hypothesis, and it would be important to have more detailed information from a geothermal survey in the region. Anyway, the observed temperature pattern and the association of freshwater with faults in the Central Region of the Pampa del Tamarugal (Fig. 29) , may indicate that Pica model, where water arises through faults after a long travel time through volcanic rocks, also applies to some ground waters in the Pampa.

3.7 Preliminary identification of faults.-

No detailed geological maps exist for most of the Pampa del Tamarugal region, except for the Pica-Chacarilla area, where springs and groundwaters are related to two well known faults. In this case, it is assumed that as waters are generated in the Altiplano and Altos de Pica, they flow through volcanic rocks and emerge through these faults.

In order to test the hypothesis of faults supplying fresh-water in the Pampa area, a preliminary tectonic map of the basement complex was prepared by J.C. Parra of the Servicio Nacional de Geología y Minería-Chile (Fig. 29). This map is based on an aeromagnetic anomaly map (1:250.000) of the region. The alignments of Fig. 29 may represent fault lines.

In the vicinity of the freswater bodies of the Central area in region 2 and at the Eastern margin of Salar de Pintados, several major NW-SE faults exist and their extension can be recognized on satellitefotographs of the Cordillera de la Costa. The existence of these subsurface faults can explain differences in chemical and isotopic composition of waters in nearby wells, which cannot be explained on the basis of a single aquifer model.

It is necessary to stress that more detailed information on tectonics and geology of subsurface is needed before any further conclusion can be drawn.

4.- GENERAL COMMENTS

Chemical data obtained in this study show clear evolution patterns of waters, according to type and intensity of interaction with rocks. The clearest evidence for these processes is contained in spring water data, which show changes in element ratios as a function of age (^{14}C content). Thus, $SO_4^{=}/Cl^-$ ratio, first high due to predominancy of sulfide oxidation processes, then decreases due to the influence of chlorine leaching. Na^+/K^+ ratio increases with age, due to dissolution of plagioclase, formation of clay minerals and probably also K-feldspar. Similar trends are recognized for flood waters which have an important component of sub-surface water, characterized by lower Na^+/Cl^- ratios and higher Na^+/K^+ ratios. It is necessary to remark that for springs waters, the above mentioned effect is not related to the total amount of salt.

Stable isotope composition of rivers (base flow) and springs looks modified relative to rain waters. Rain waters have a deuterium excess of about +13, whereas rivers and springs have "d" values close to +5. This difference suggests evaporation during rain fall and in the recharge areas, following a slope of not less than 7. With increasing flowpath (and increasing salinity), river waters become enriched in heavy isotopes along an evaporation line of slope 5. An exception to this are the Tarapacá river waters, which show no deviation from an 8-slope-line along the flowpath, although there is an enrichment in ^{18}O, ^{2}H and salt contents.

Groundwaters in the Pampa del Tamarugal show chemical compositions determined by processes in the recharge area and additional dissolution of evaporites and base exchange reactions with clay minerals. Waters of the Western edge generally are older (lower ^{14}C content) and more saline, with Na^+/Cl^- ratios close to 1, reflecting dissolution of halite as the main salt source.

From the point of view of groundwater resources, the most interesting waters are those found in the Central part of the Pampa (regions 2 and 4, with E.C. values of less than 1500 μmhos). These waters do not look evolved from river wa-

ters. Though they reflect longer interaction times with volcanic rocks, they show less salinity . These low salinity waters could be associated to deeper formations and emerge to surface due to existence of faults. Examples to this are the Pica and Esmeralda areas, where waters of different chemistry, isotopic composition and age emerge along faults.

Central Pampa groundwaters are less than 5000 years old, and younger by al least 5000 years than the waters found in the Western and Eastern margin (Canchones,DGA 131)

In conclusion, the analysis of chemical and isotopic data and aquifer temperatures, which are higher than the mean annual temperature, suggest that most of the Central Pampa groundwaters are recharged from beneath, after a long interaction with volcanic rocks, and their emergence may be associated to faults. Good quality waters should be taken close to the fault, before they become saline as a result of salt dissolution and mixing in the sedimentary filling of the Pampa del Tamarugal.

5.- RECOMMENDATIONS FOR FUTURE STUDIES.-

In order to test the hypothesis presented in this study, in the sense of relating the less saline groundwaters to the existence of faults, following studies should be carried out:

1) A detailed thermal study of the Pampa del Tamarugal, which should include temperature logging in all the wells and determination of heat flow.

2) A detailed structural geological map of the region.

3) A detailed map of the basement of sedimentary filling should be made, relating this information to satellite, magnetic and seismic data of the region.

4) For a better understanging of the isotopic evolution of the rain, a project of simultaneous sampling of daily rain along a transect from the Amazon basin through the Andes should be carried out. Since the project needs the participation of several countries, it should be organized by IAEA or another International Organization.

5) Radon measurements either in groundwater or in soil could be used to detect some possible deep groundwater sources. The required equipment is available at CChEN.

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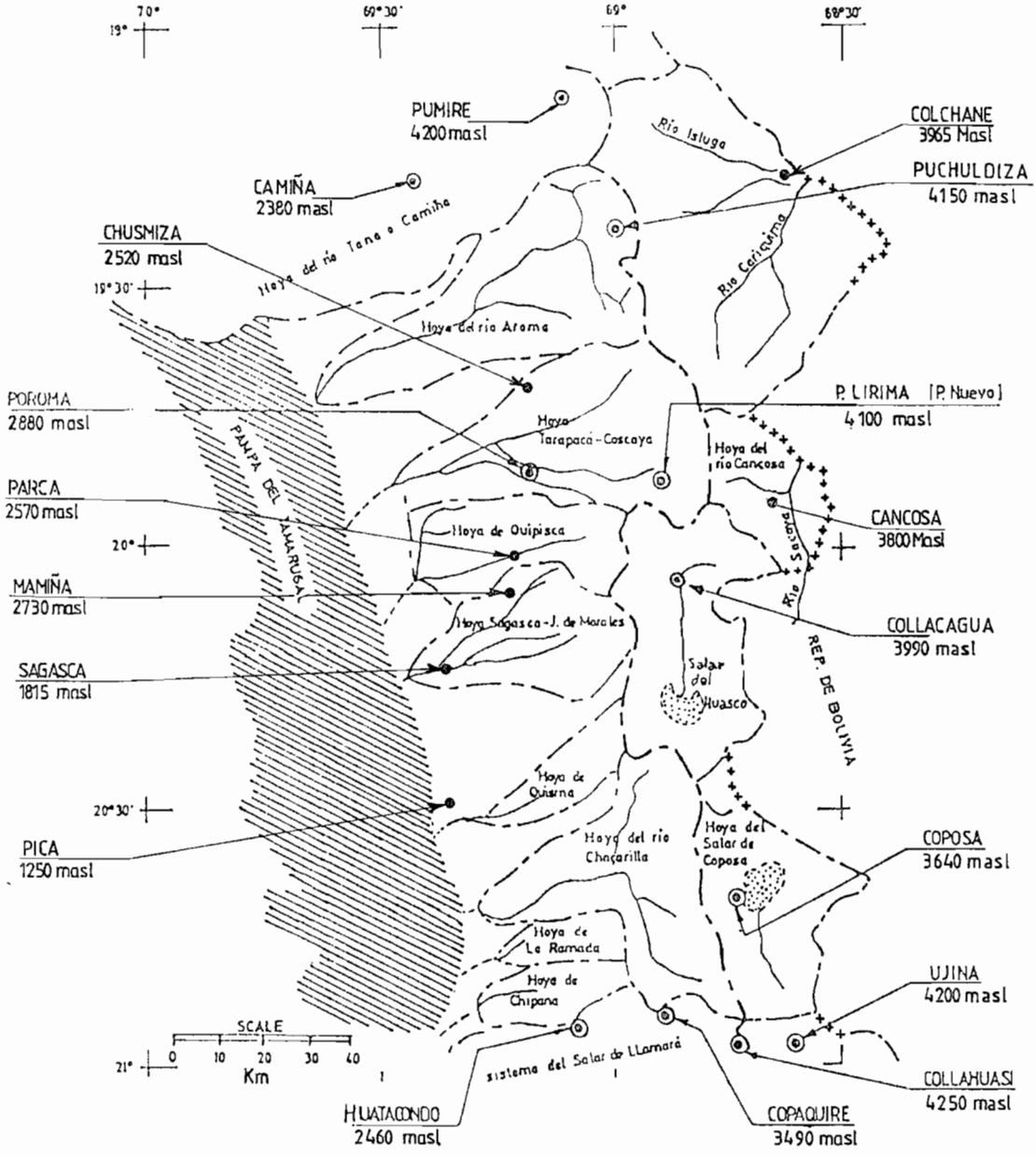
FIGURES

FIG. 1

LOCATION MAP OF RAIN STATIONS



SYMBOLS

+++++ INTERNATIONAL BOUNDARY

— — — BASIN BOUNDARY PAMPA-ALTIPLANO

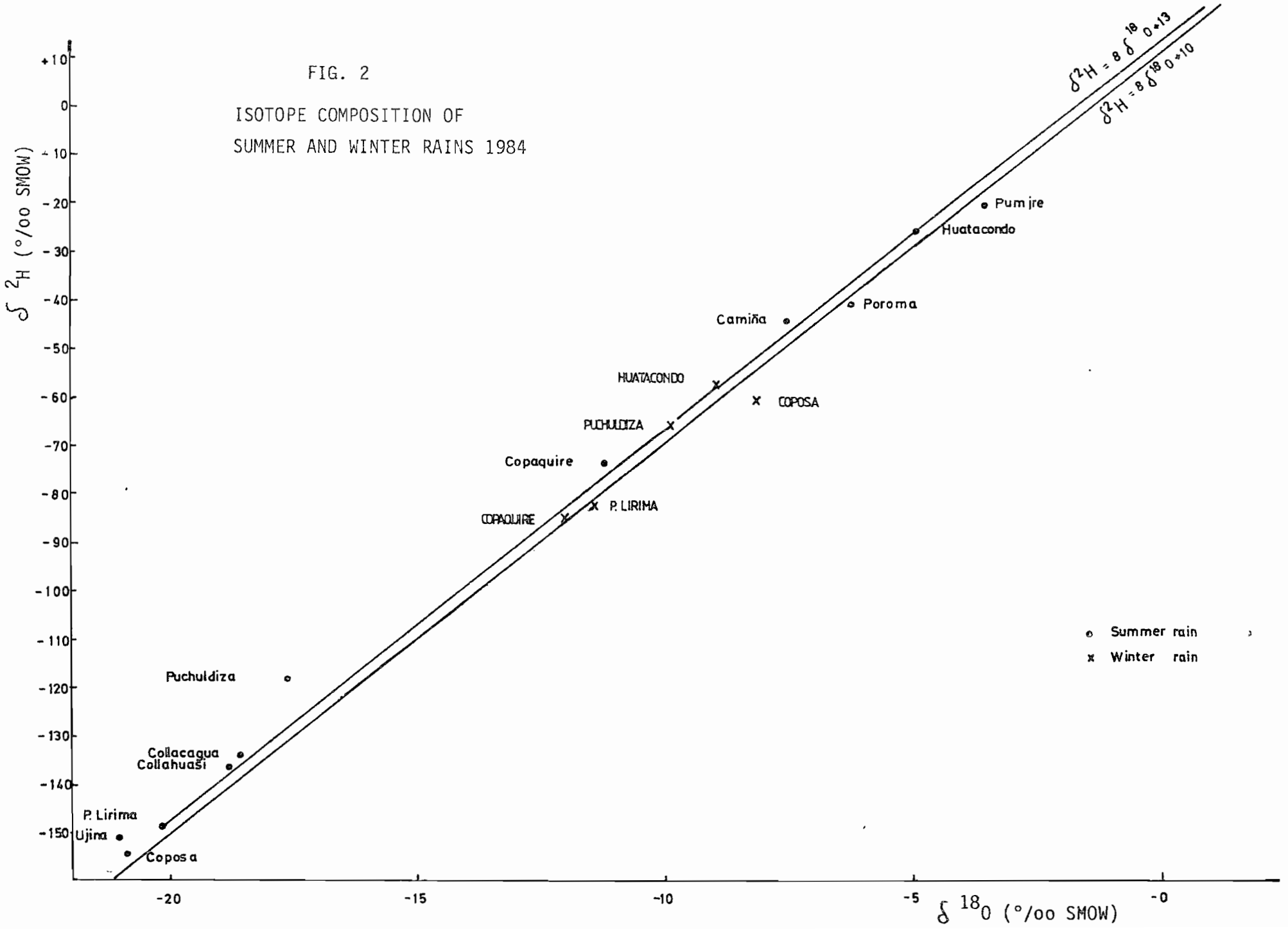
— - — HIDROGRAPHIC BASIN BOUNDARY

◎ SAMPLED RAIN STATIONS

○ NOT SAMPLED RAIN STATIONS

FIG. 2

ISOTOPE COMPOSITION OF
SUMMER AND WINTER RAINS 1984



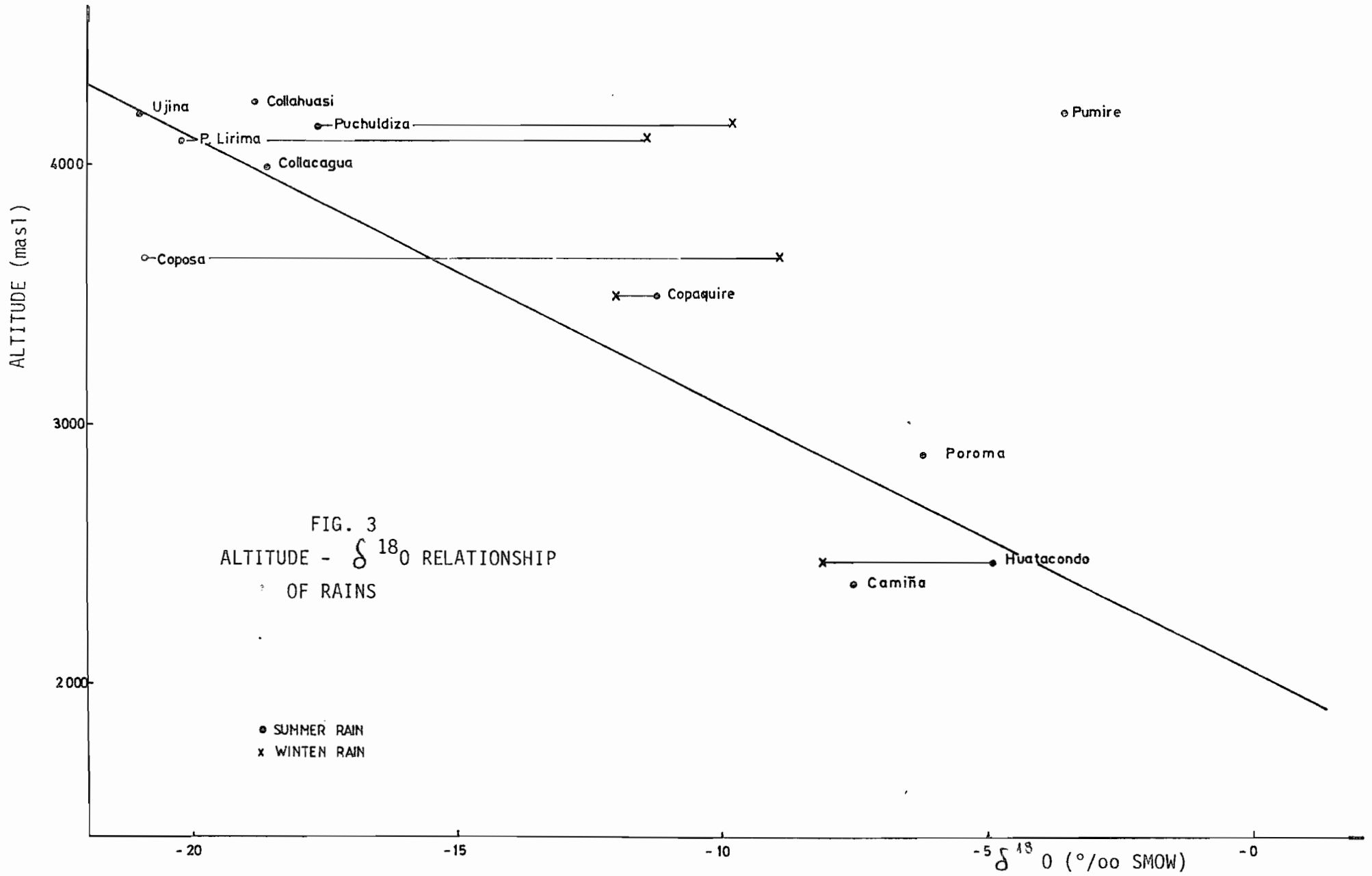
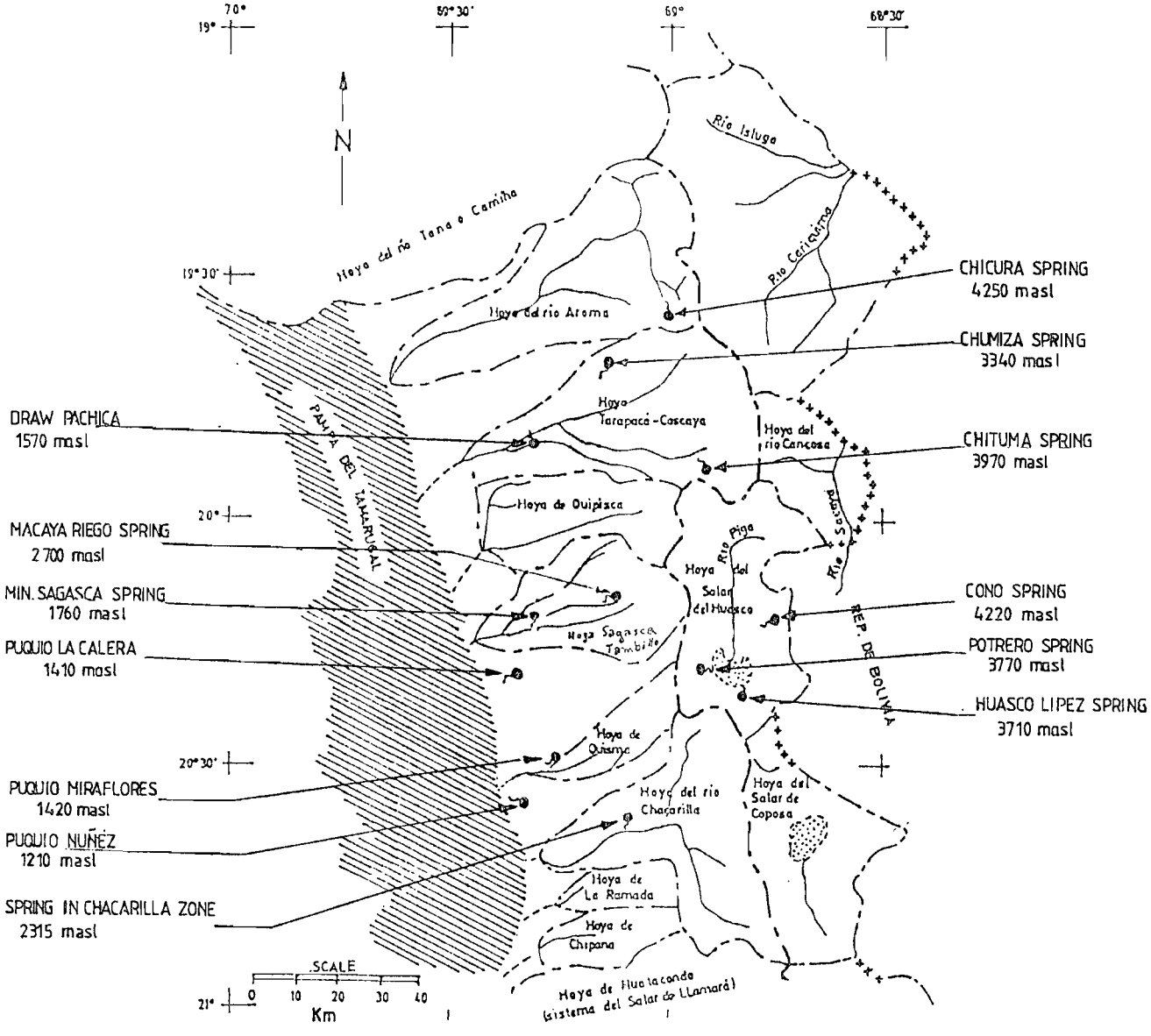


FIG. 3
ALTITUDE - $\delta^{18}O$ RELATIONSHIP OF RAINS

FIG. 4

LOCATION MAP OF SAMPLED SPRINGS



SYMBOLS

+++++ INTERNATIONAL BOUNDARY

— — — BASIN BOUNDARY PAMPA-ALTIPLANO

— — — HIDROGRAPHIC BASIN BOUNDARY

SAMPLED SPRING

FIG. 5

ISOTOPIC COMPOSITION

OF RIVER AND SPRING WATERS

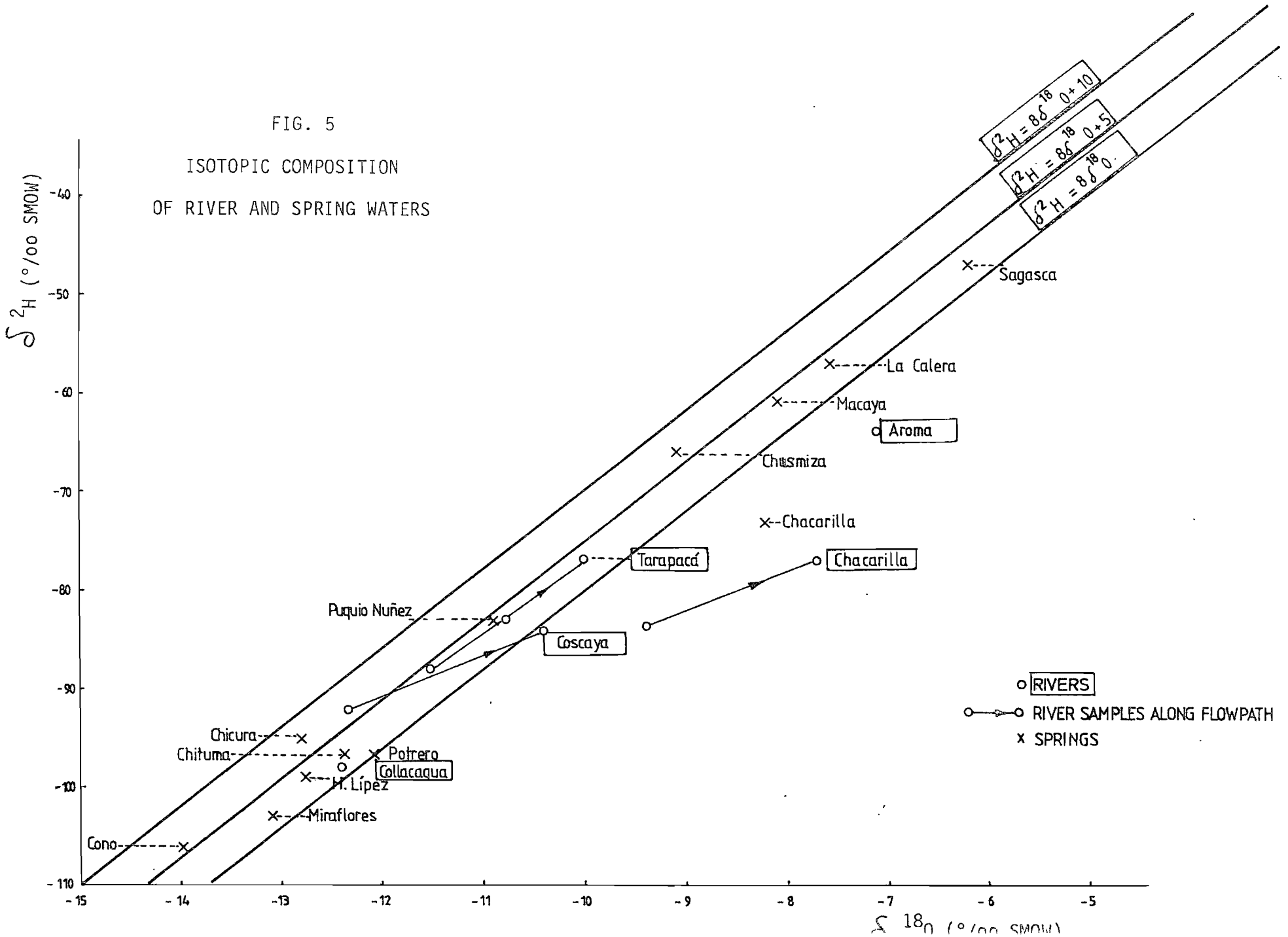


FIG. 6 A

RIVERS

Na^+/Cl^- ratio vs E.C.

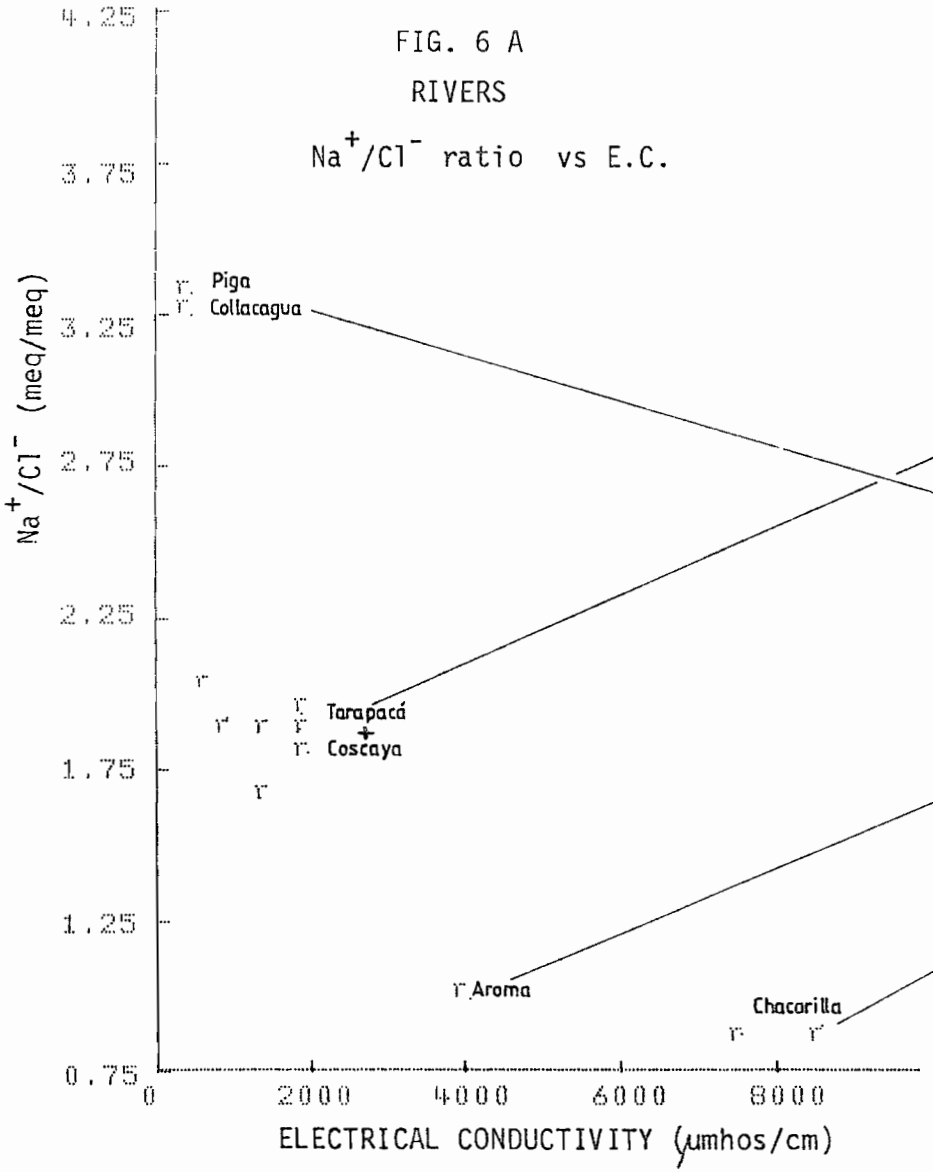


FIG. 6 B

SPRINGS

Na^+/Cl^- ratio vs E.C.

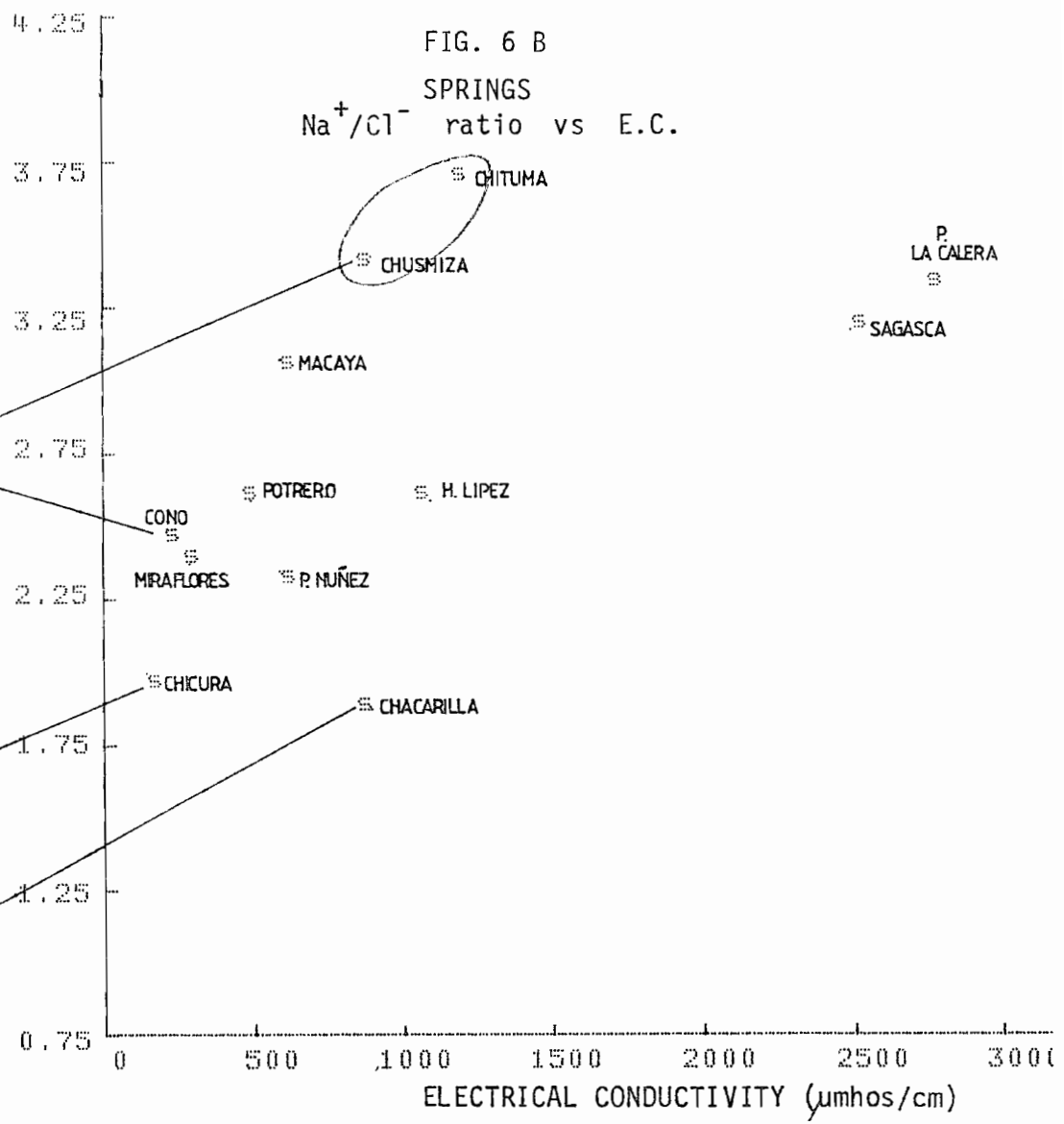


FIG. 7 A

RIVERS

$SO_4^=$ vs Cl^- content

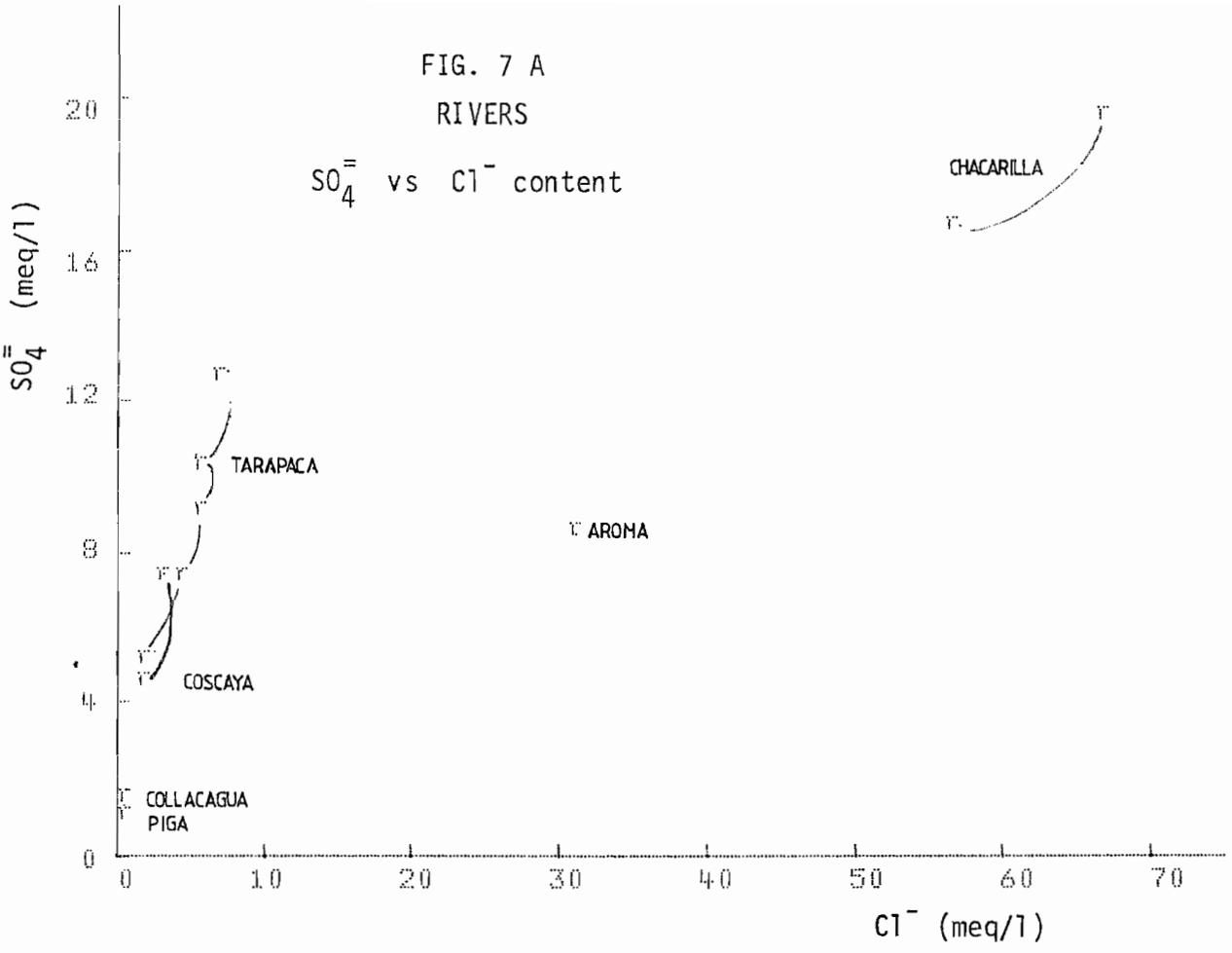


FIG. 7 B

SPRINGS

$SO_4^=$ vs Cl^- content

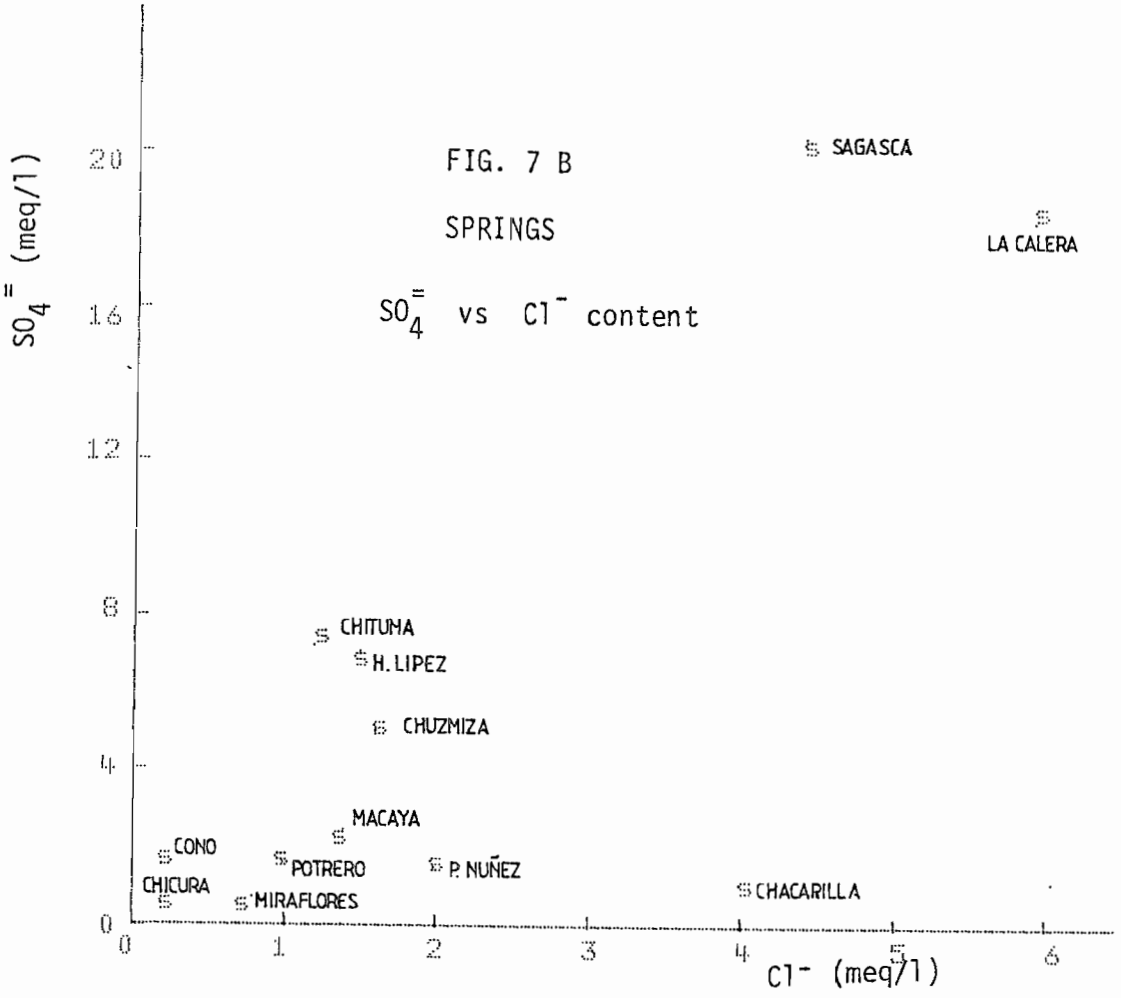


FIG. 8

SPRINGS AND RIVERS

Na^+/K^+ ratio vs C-14 content

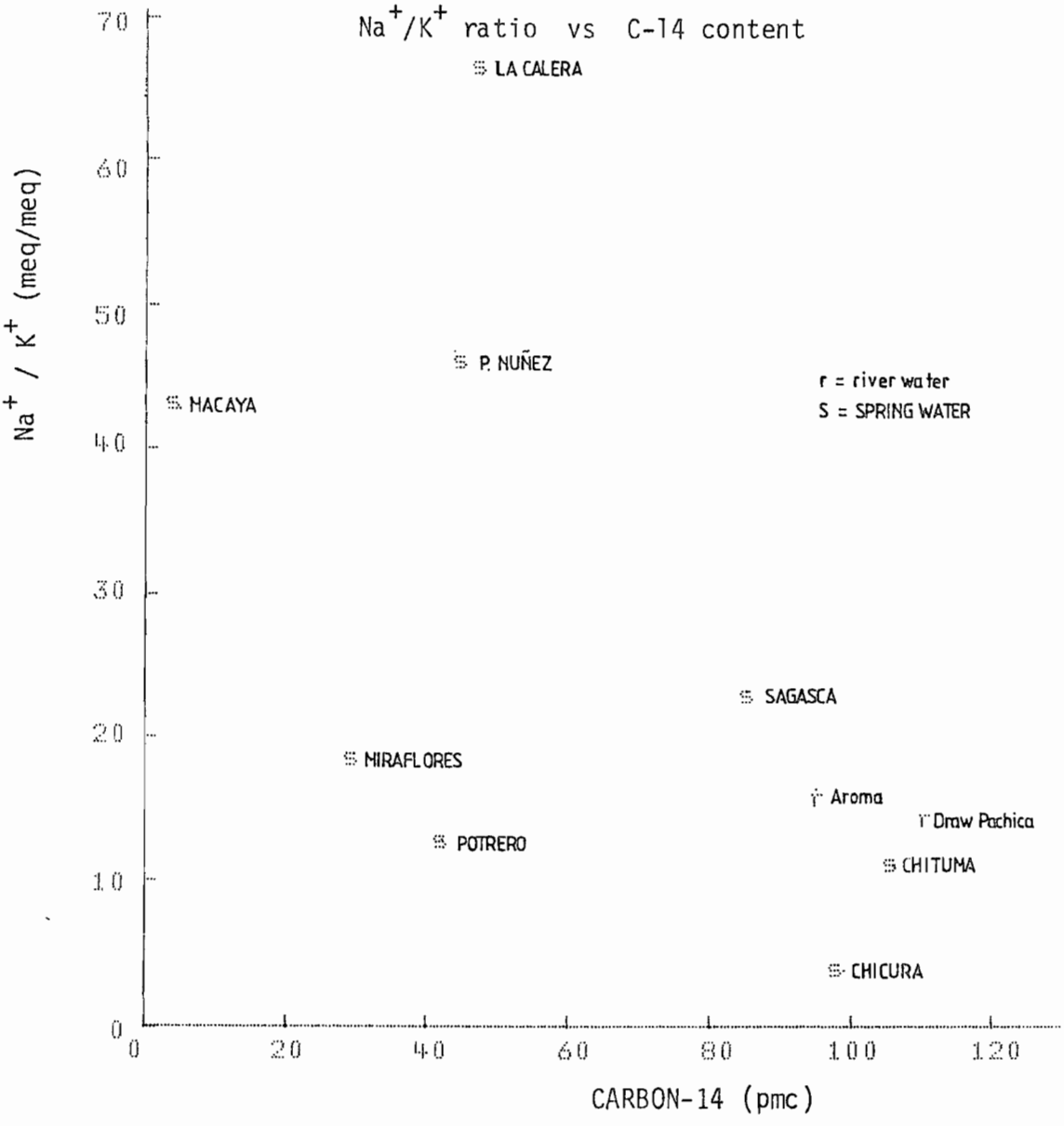
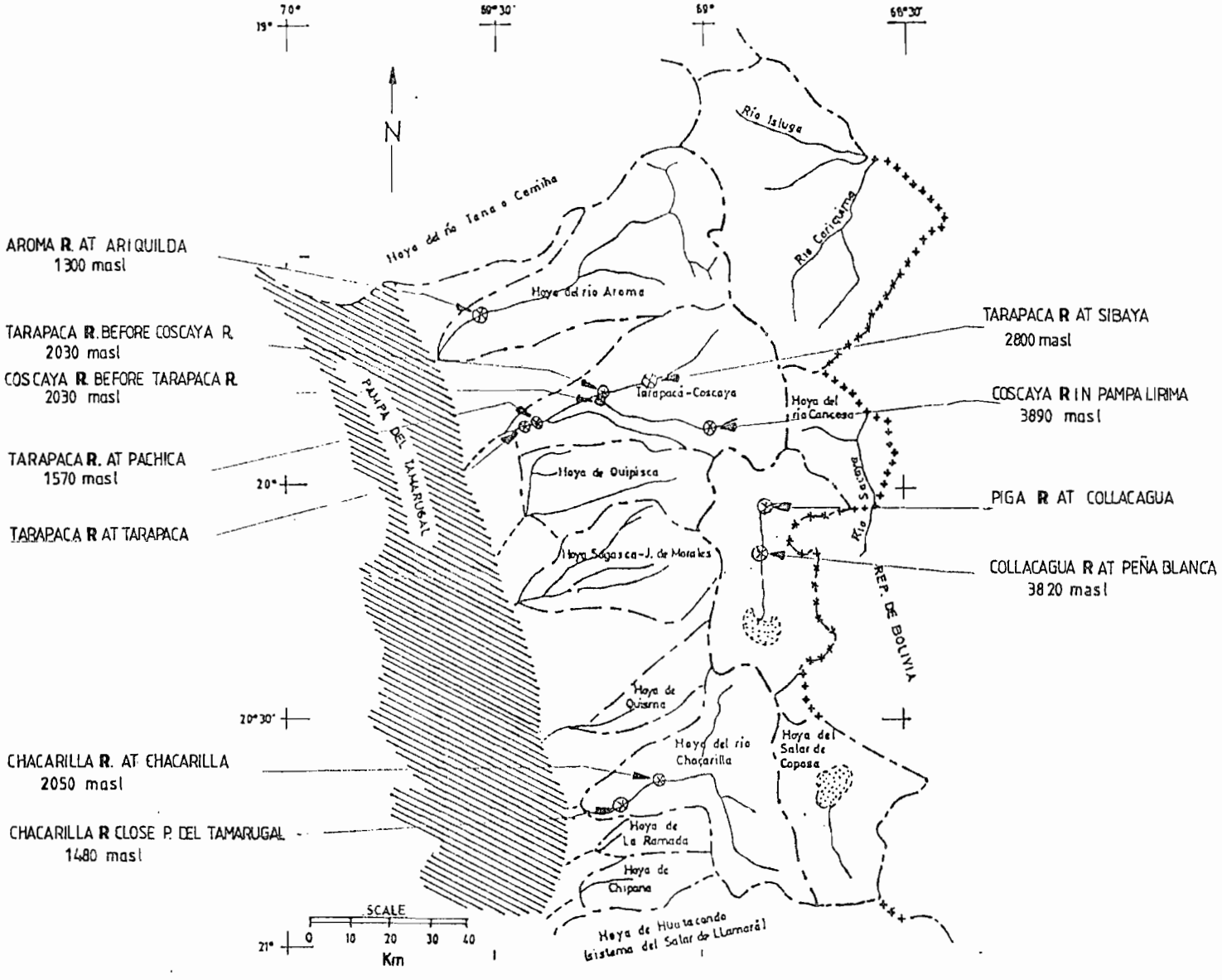


FIG. 9

LOCATION MAP OF RIVER WATER SAMPLING POINTS



SYMBOLS

+++++ INTERNATIONAL BOUNDARY

— — — BASIN BOUNDARY PAMPA-ALTIPLANO

— · — HIDROGRAPHIC BASIN BOUNDARY

⊗ SAMPLING POINT

FIG. 10

TARAPACA RIVER AT PACHICA

Na^+/Cl^- ratio vs E.C.

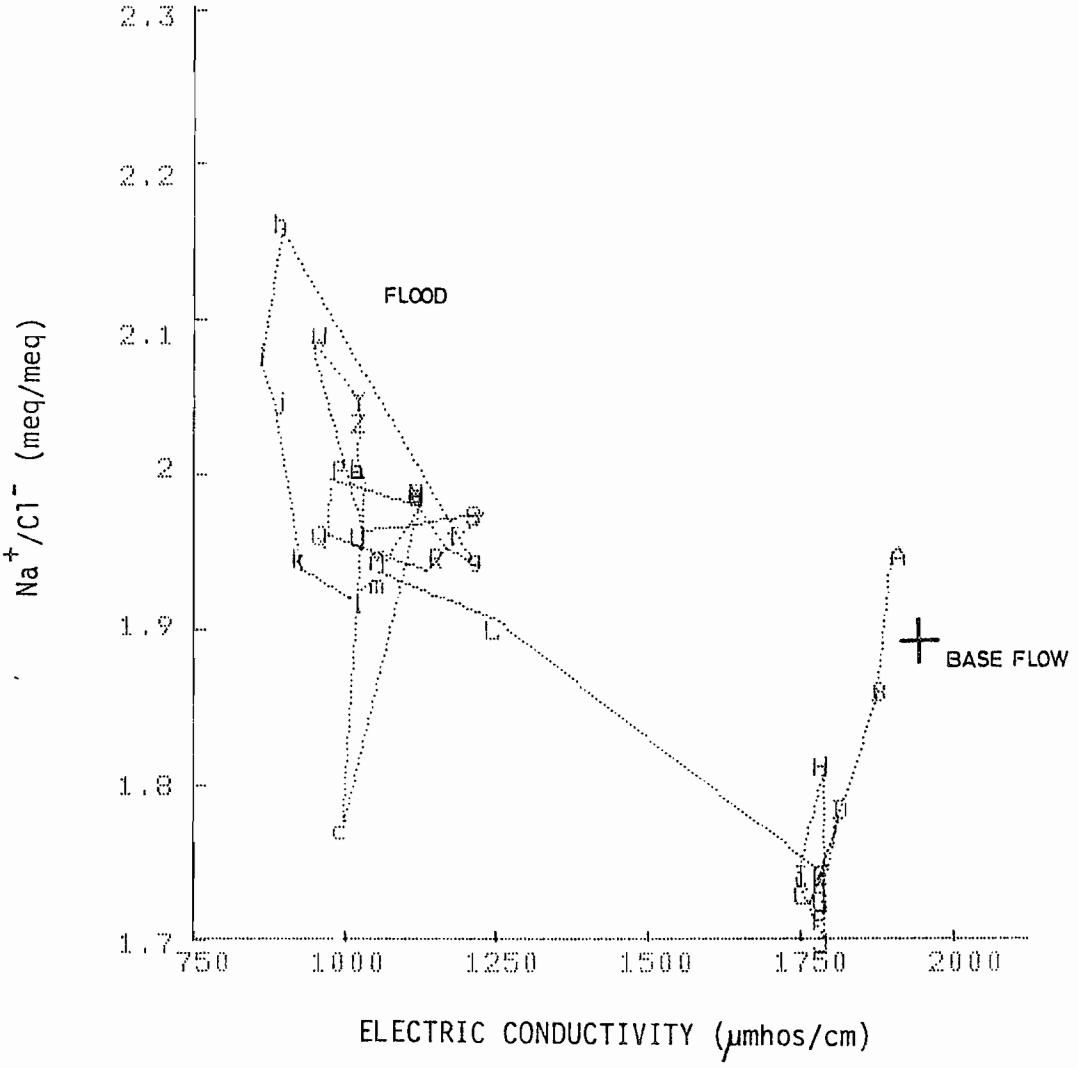


FIG. 11 A

TARAPACA RIVER AT PACHICA

Na^+/K^+ vs Na^+/Cl^- ratio

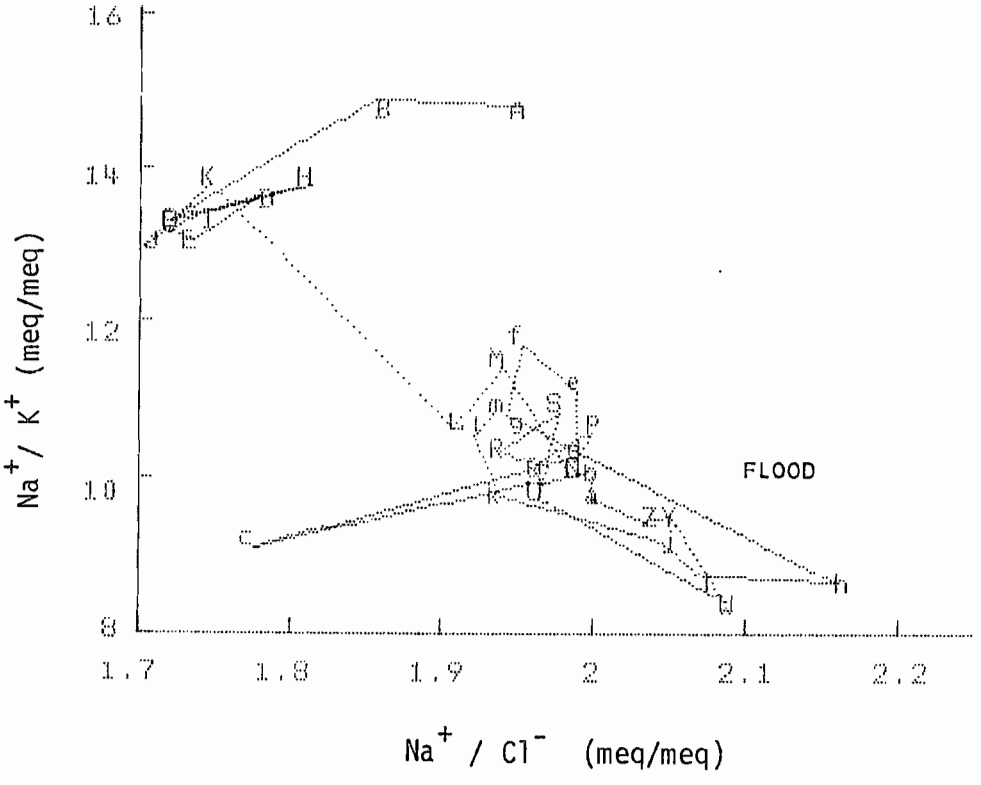


FIG. 11 B

TARAPACA RIVER AT PACHICA

$SO_4^=/Cl^-$ vs Na^+/Cl^- ratio

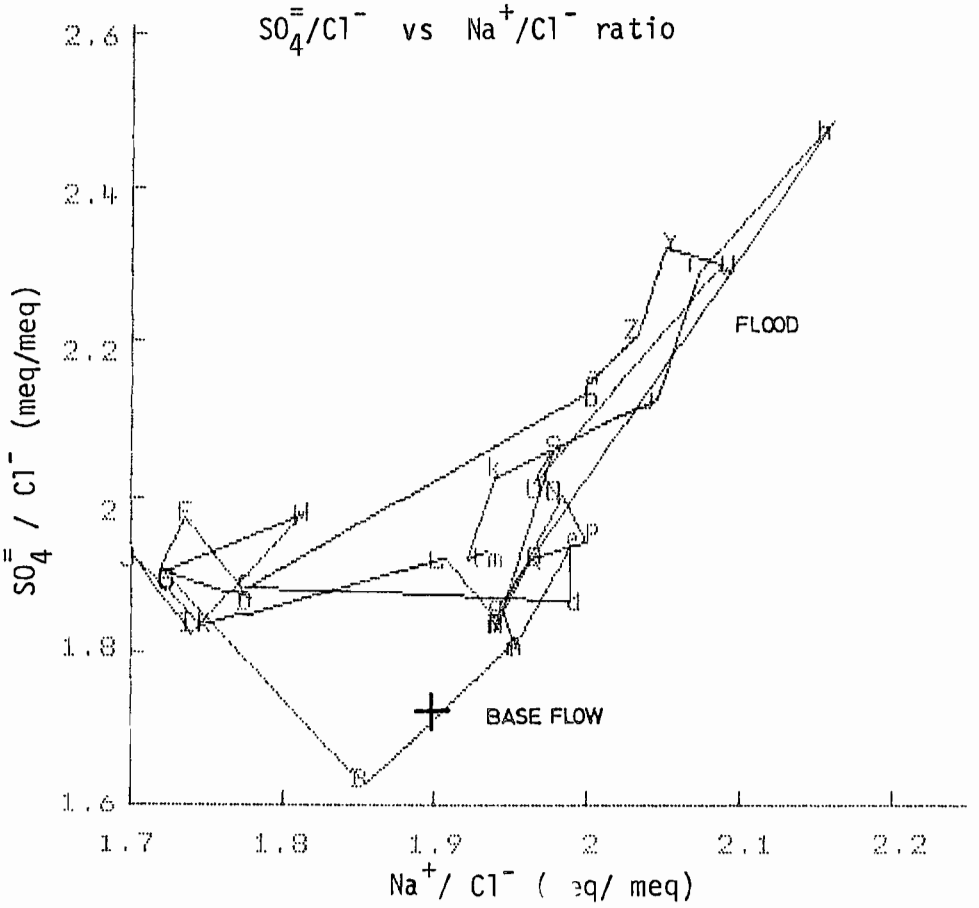


FIG. 12 A

AROMA RIVER AT ARIQUILDA

Na^+/Cl^- ratio vs E.C.

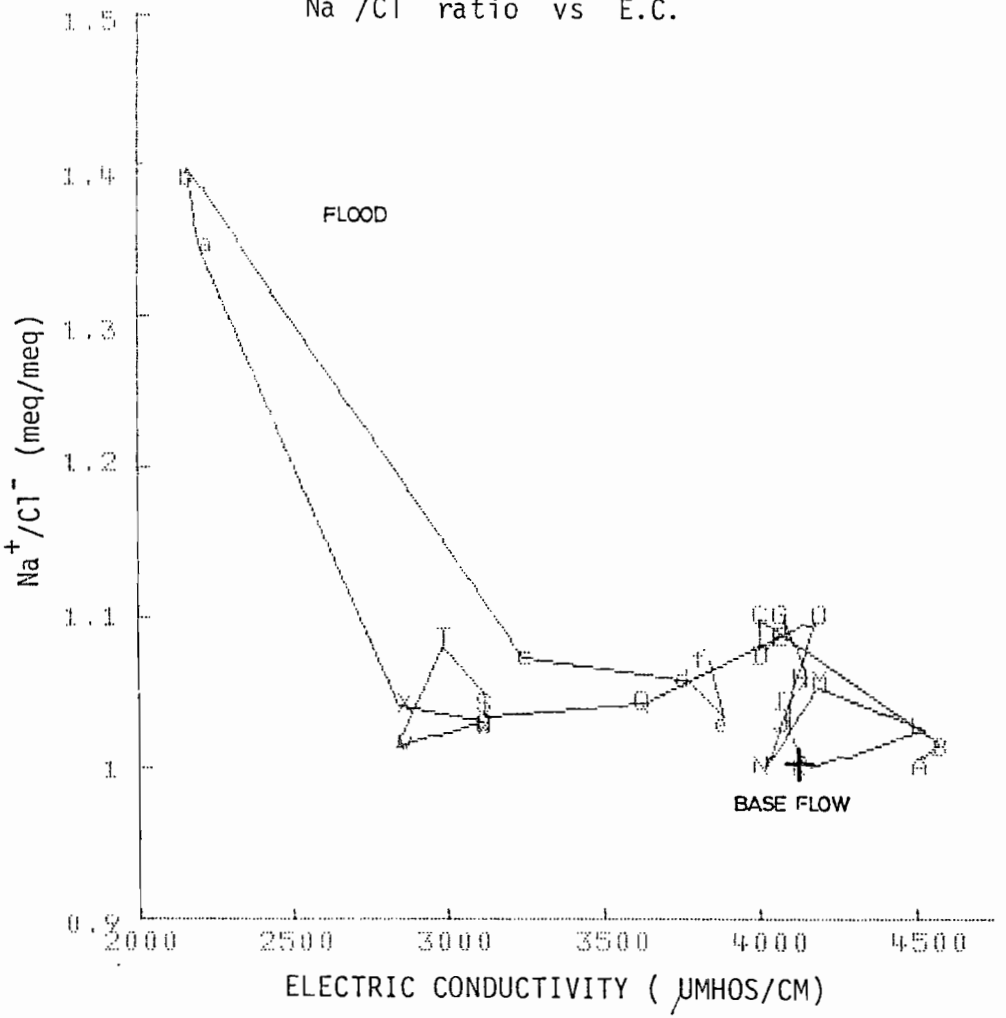


FIG. 12 B

AROMA RIVER AT ARIQUILDA

$SO_4^= / Cl^-$ ratio vs E.C.

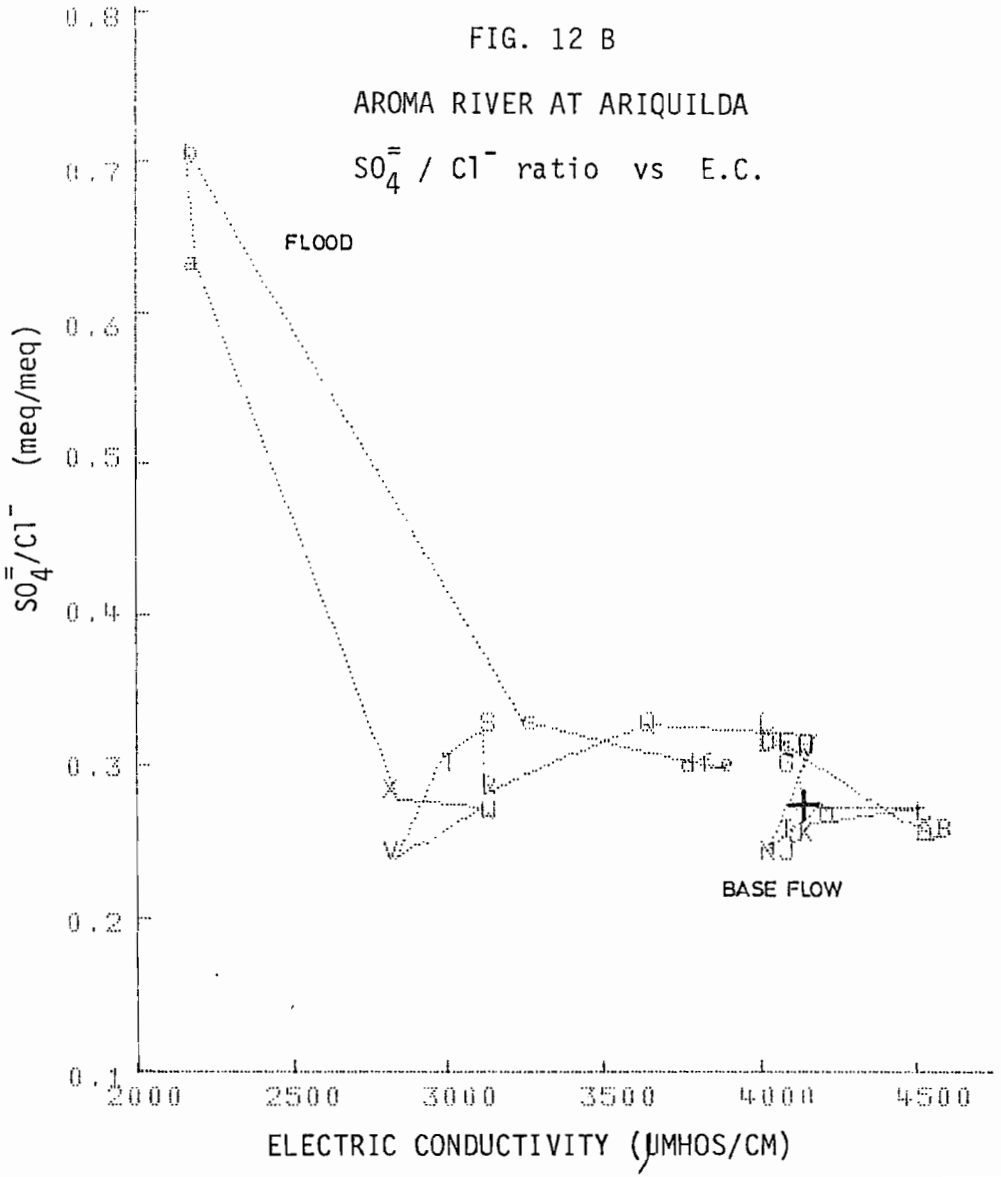


FIG. 13 A

AROMA RIVER AT ARIQUILDA

Na^+/K^+ ratio vs E.C.

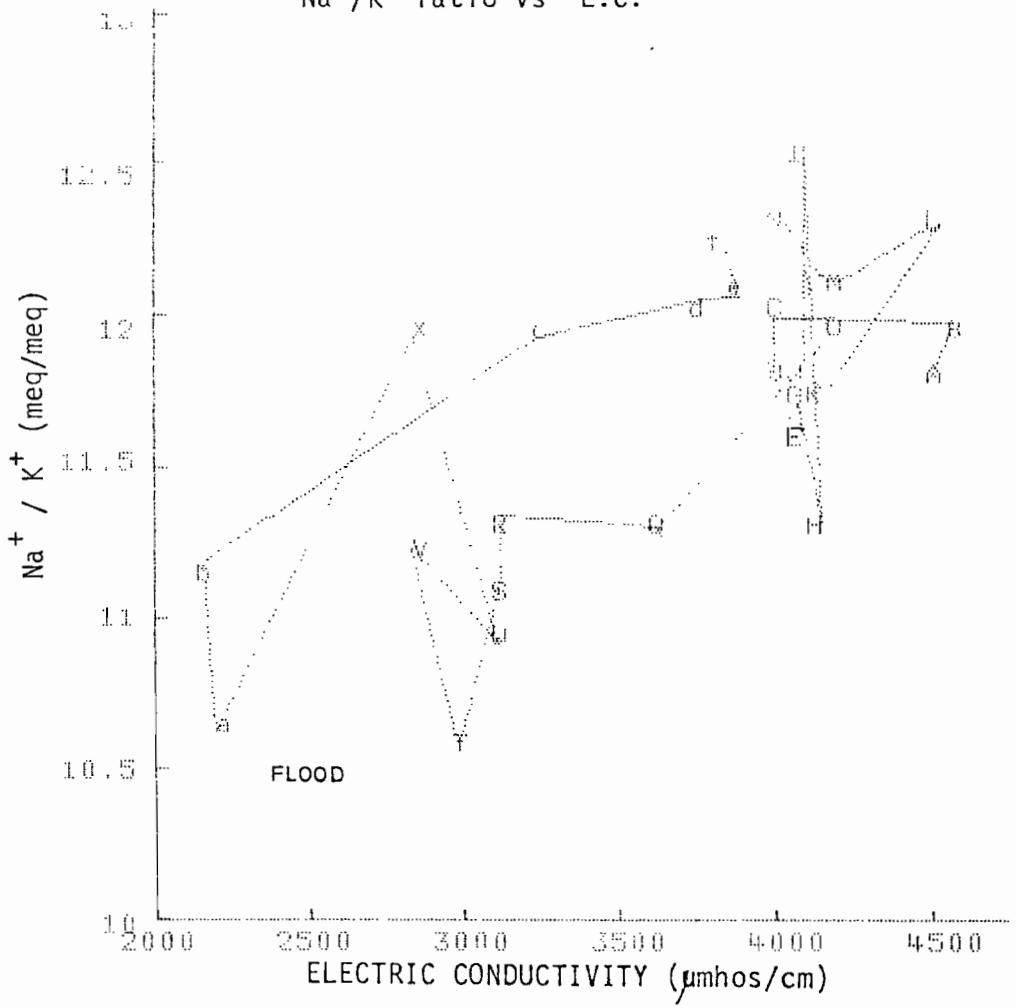


FIG. 13 B

AROMA RIVER AT ARIQUILDA

$SO_4^= / Cl^-$ vs Na^+/Cl^- ratio

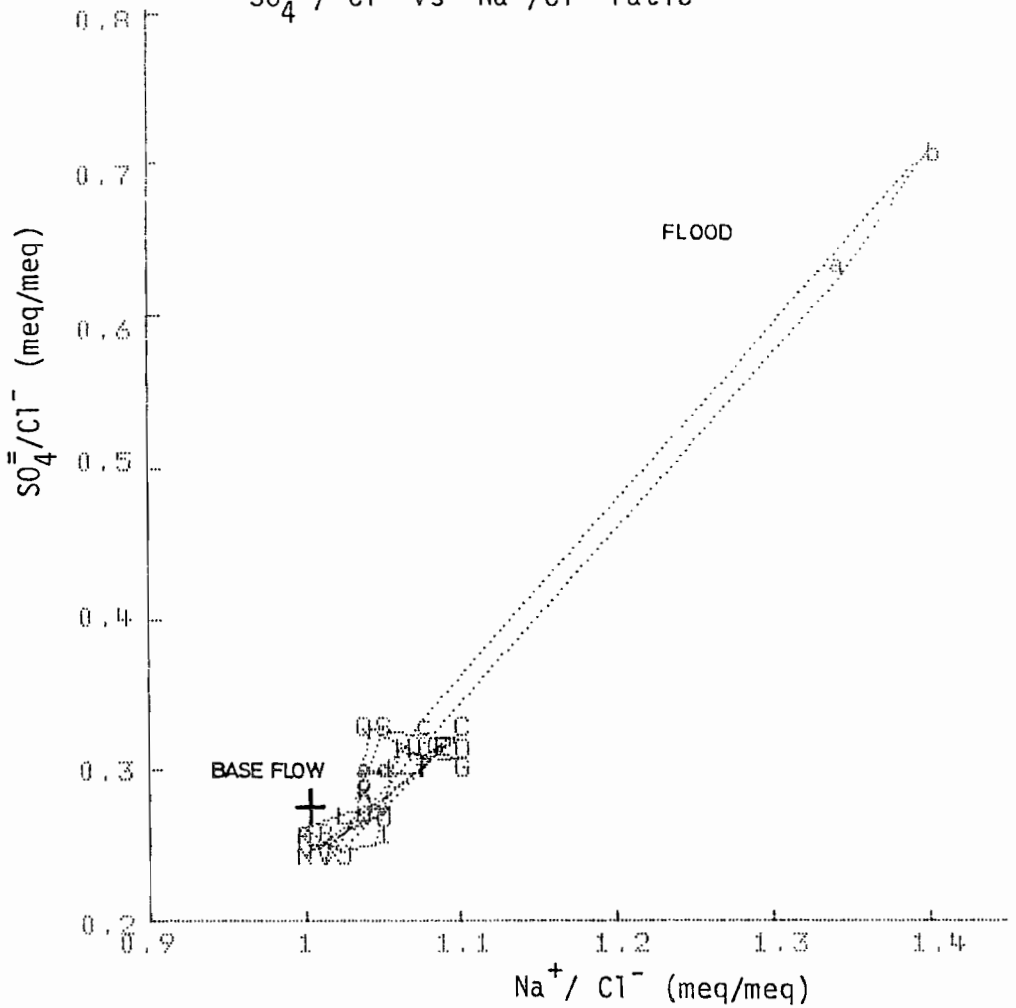


FIG. 14

LOCATION MAP OF SAMPLED WELLS AND IDENTIFIED GROUNDWATER REGIONS

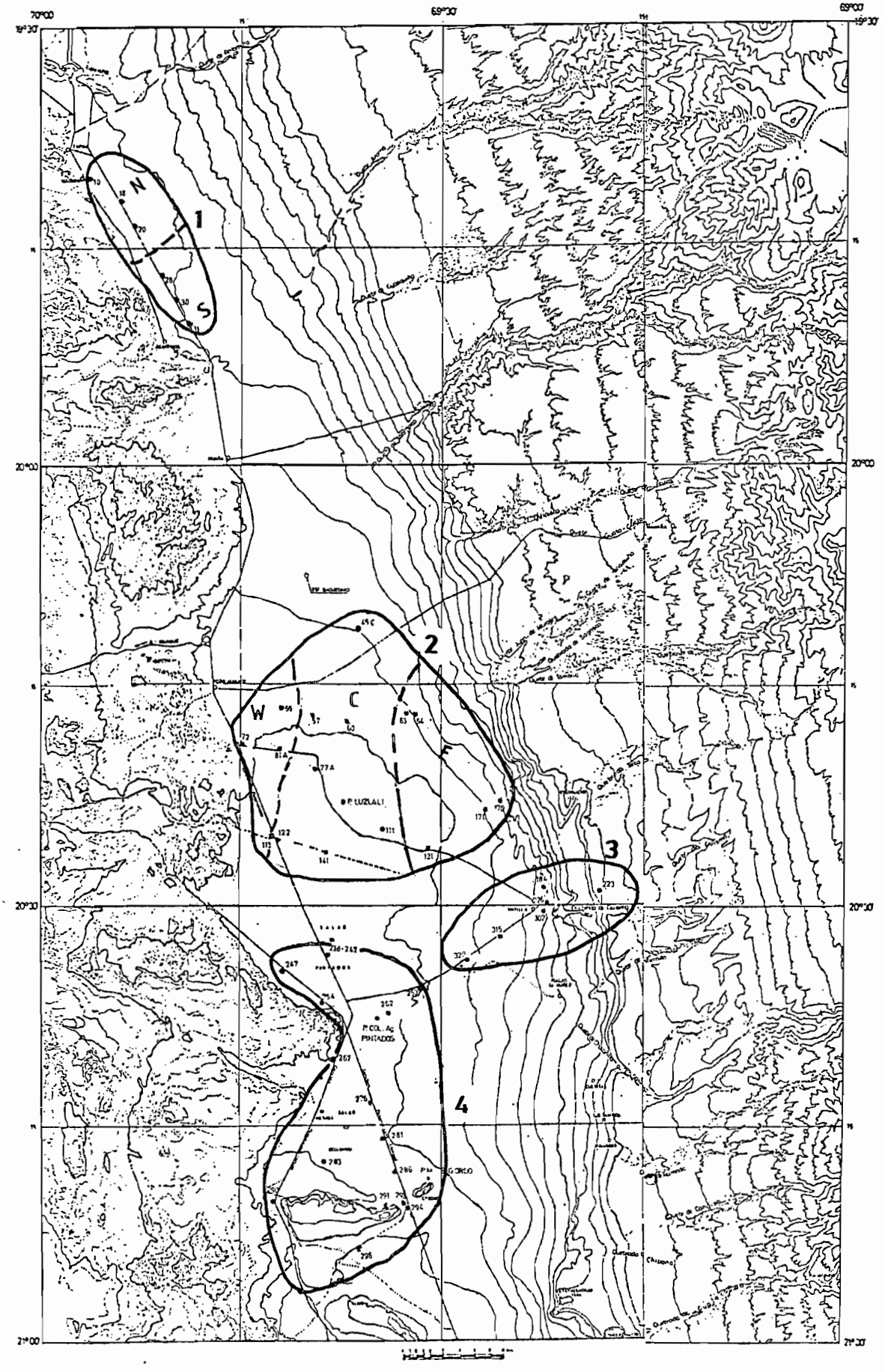


FIG. 15

ISOTOPIC COMPOSITION

OF GROUNDWATERS

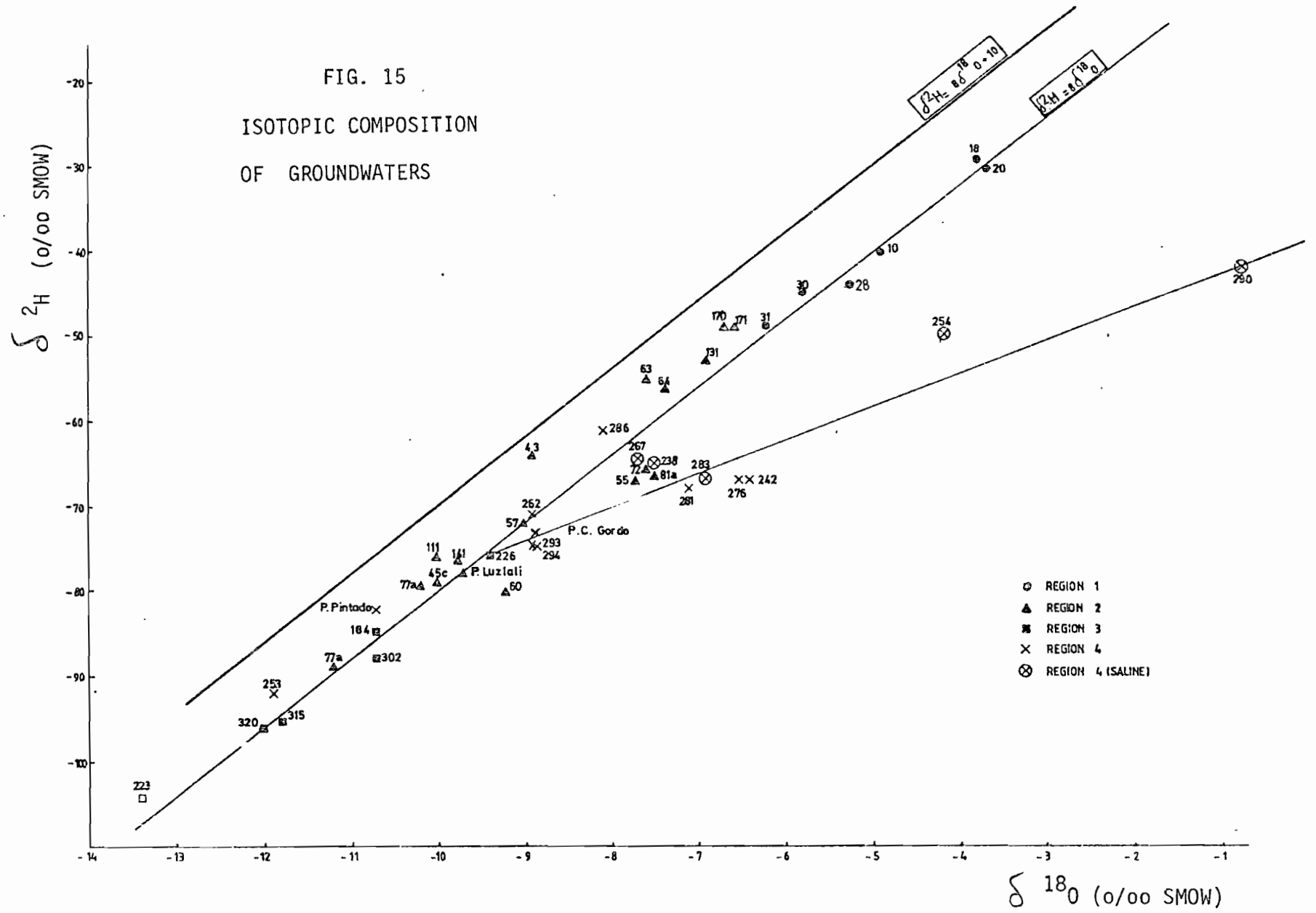


FIG. 17 A

REGION A: GROUNDWATERS AND AROMA RIVER

$\delta^{18}O$ vs $SO_4^{=}/Cl^{-}$ ratio

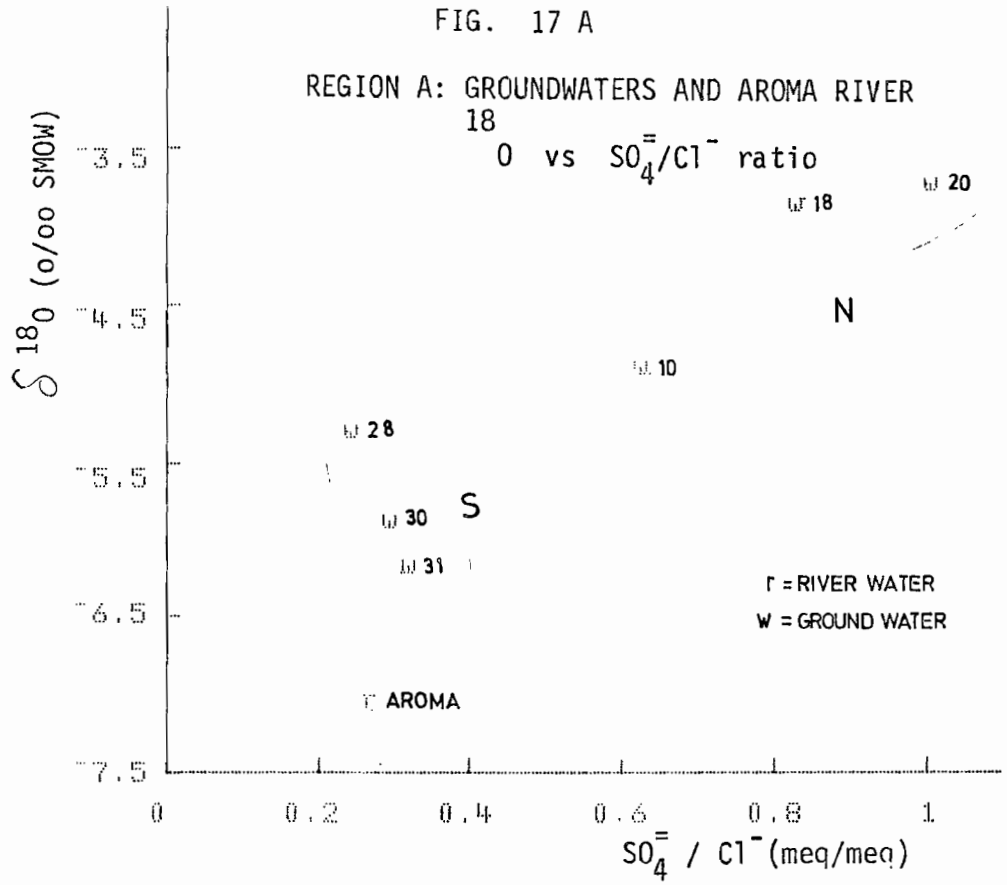


FIG. 17 B

REGION 1: GROUNDWATERS AND AROMA RIVER

^{18}O vs Na^{+} / K^{+} ratio

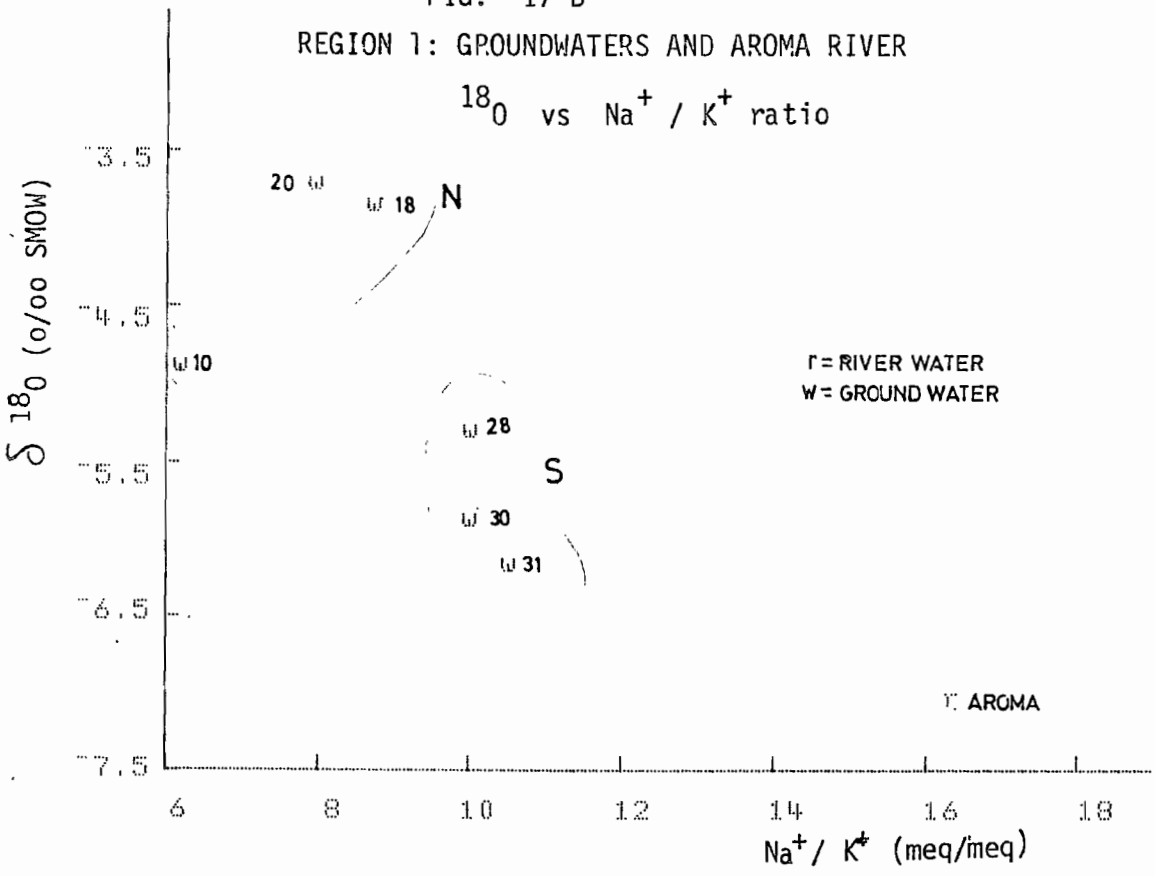


FIG. 16 A

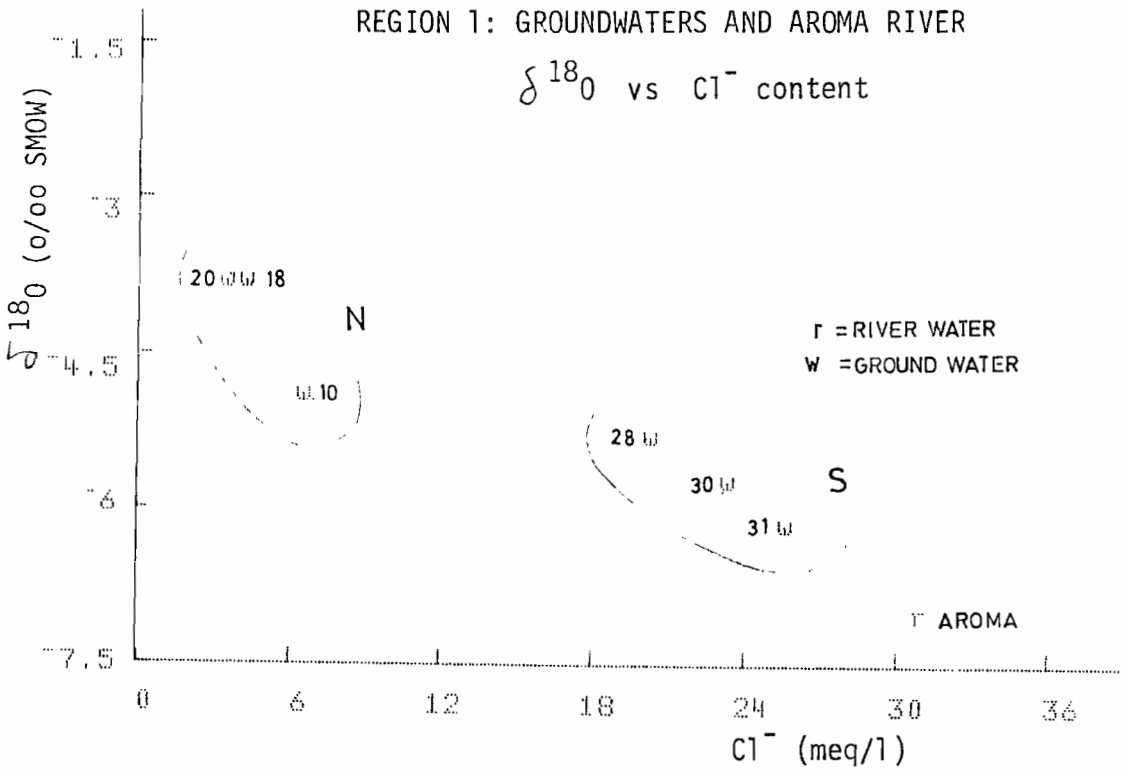


FIG. 16 B

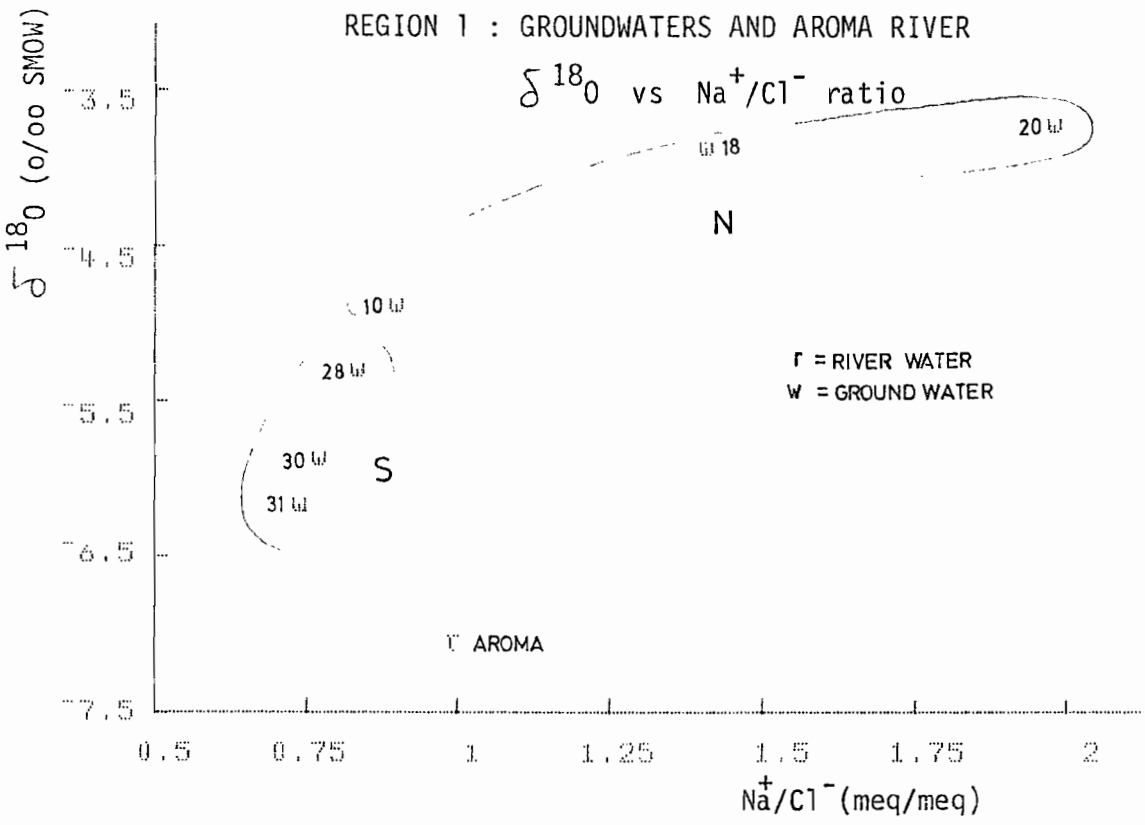


FIG. 18 A

REGION 2: ISOTOPIC COMPOSITION OF GROUNDWATERS, SPRINGS AND TARAPACA RIVER

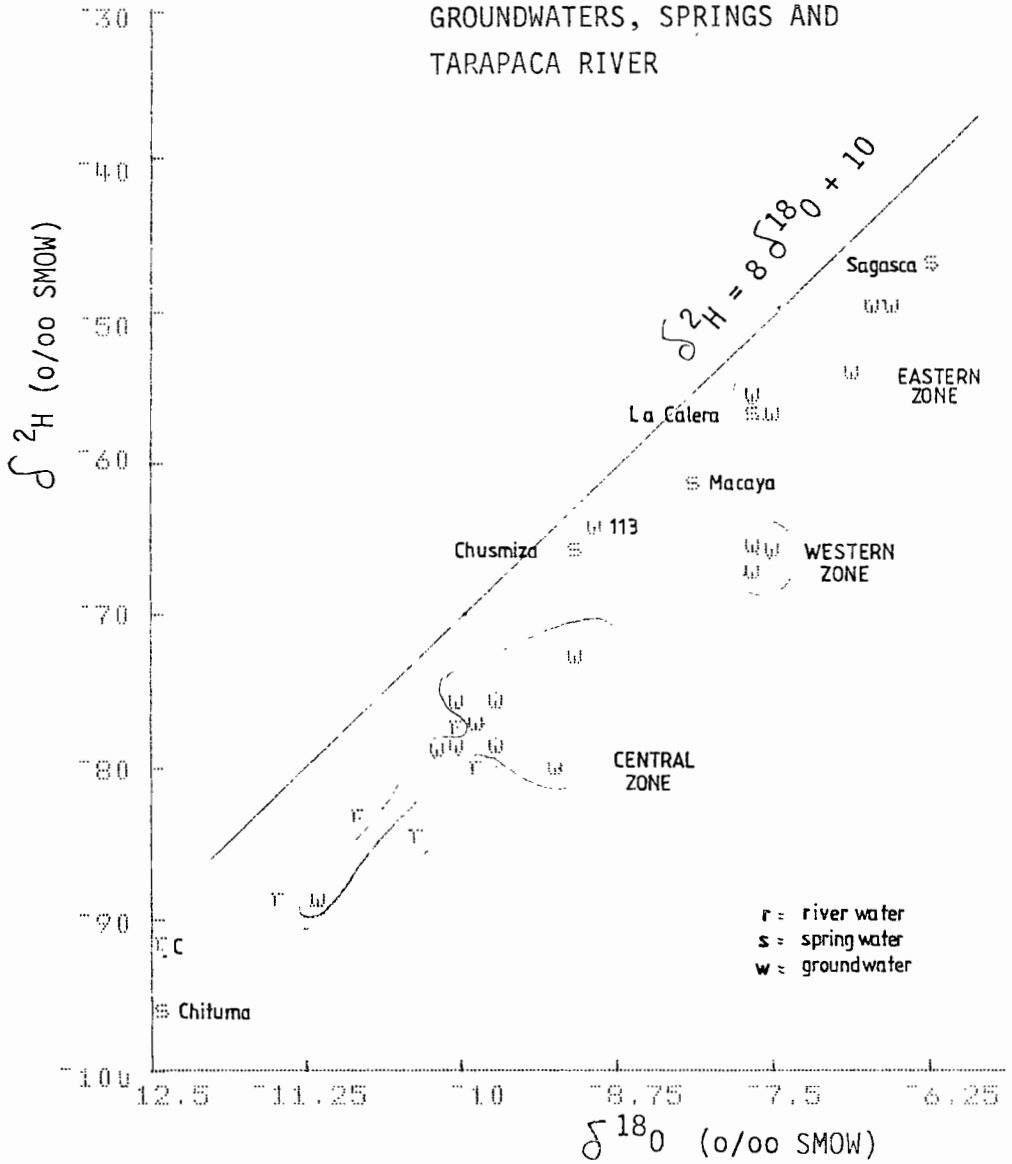


FIG. 18 B

REGION 2: GROUNDWATERS, SPRINGS AND TARAPACA RIVER
^{18}O vs ^{14}C content

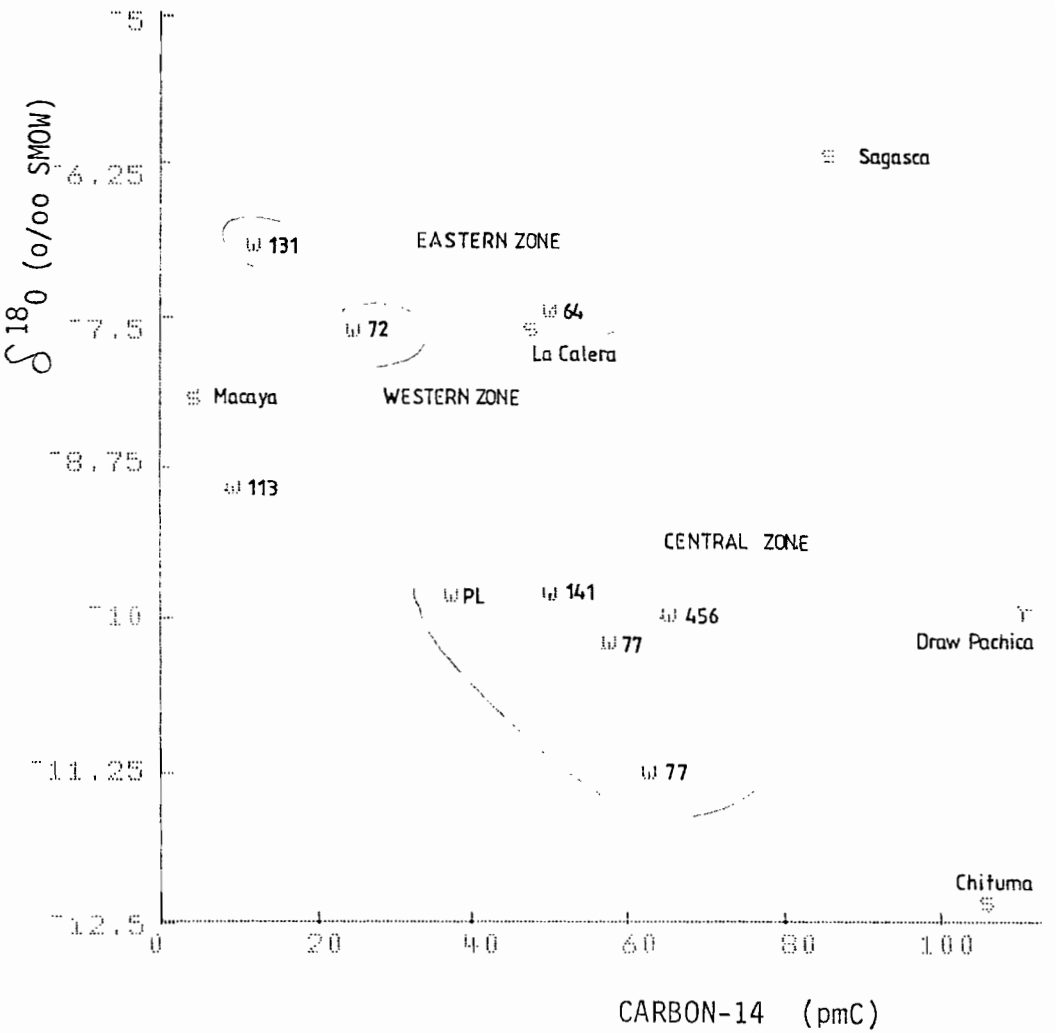


FIG. 19

REGION 2: GROUNDWATERS, SPRINGS AND TARAPACA RIVER

$\delta^{18}O$ vs Cl^- content

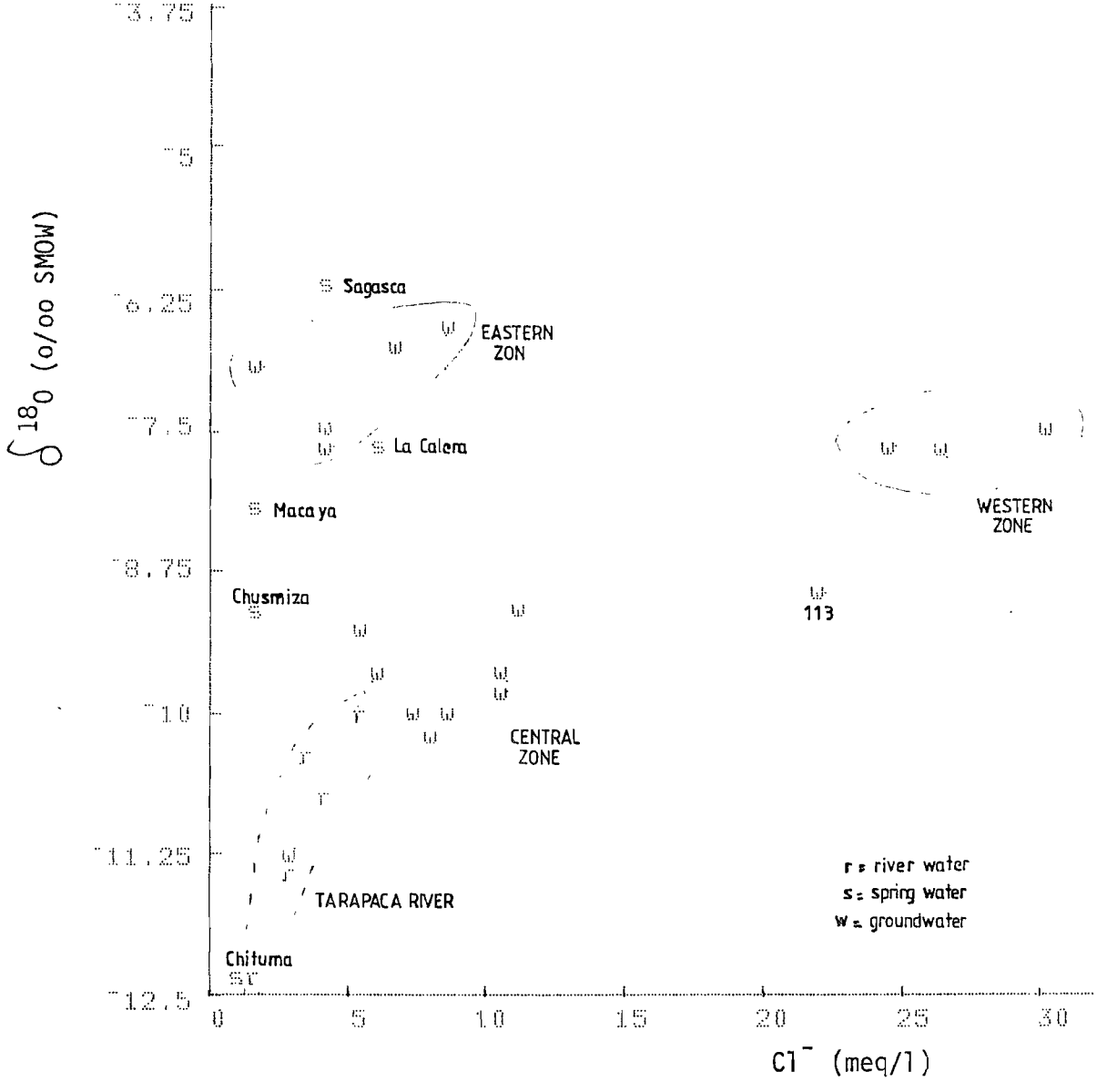


FIG. 20 A

REGION 2: GROUNDWATERS, SPRINGS AND TARAPACA RIVER

Na^+/Cl^- vs Na^+/K^+ ratio

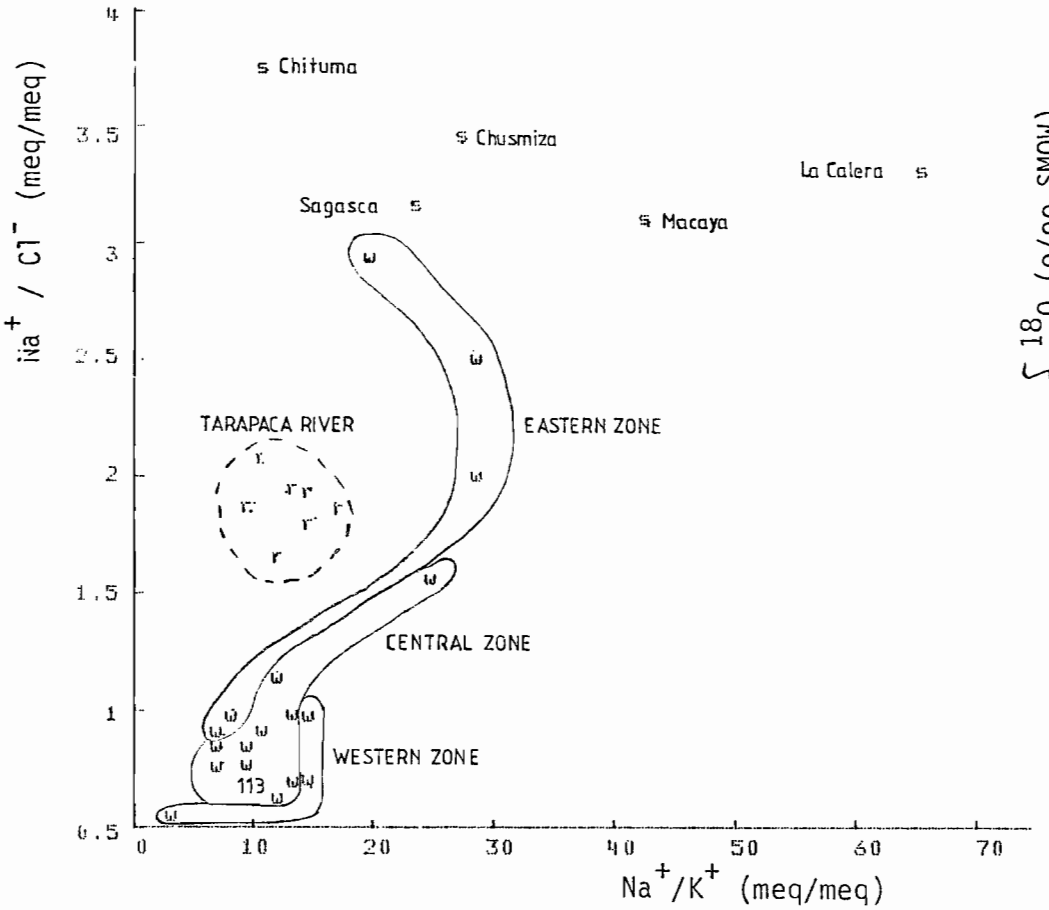


FIG. 20 B

REGION 2: GROUNDWATERS, SPRINGS AND TARAPACA RIVER

$\delta^{18}O$ vs Na^+/Cl^- ratio

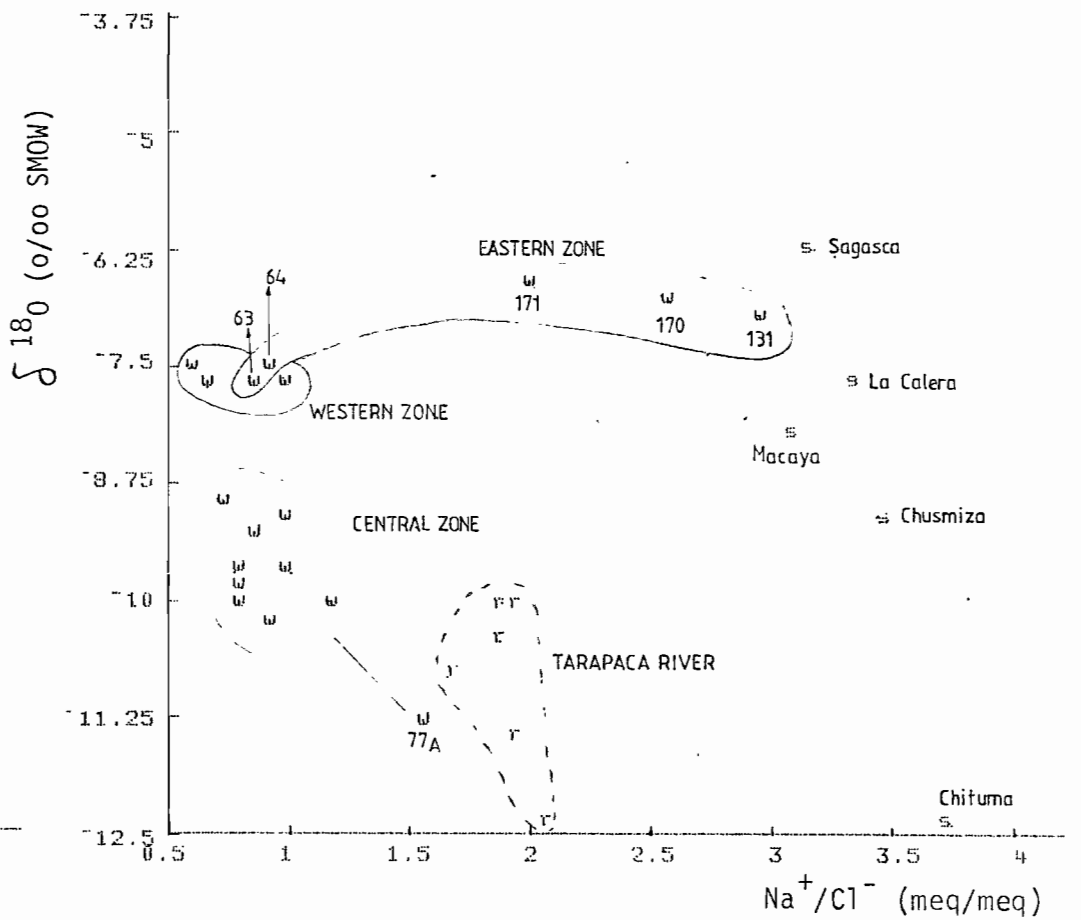


FIG. 21 A

REGION 2: GROUNDWATERS, SPRINGS AND TARAPACA RIVER

$\delta^{18}O$ vs $SO_4^{=}$ / Cl^- ratio

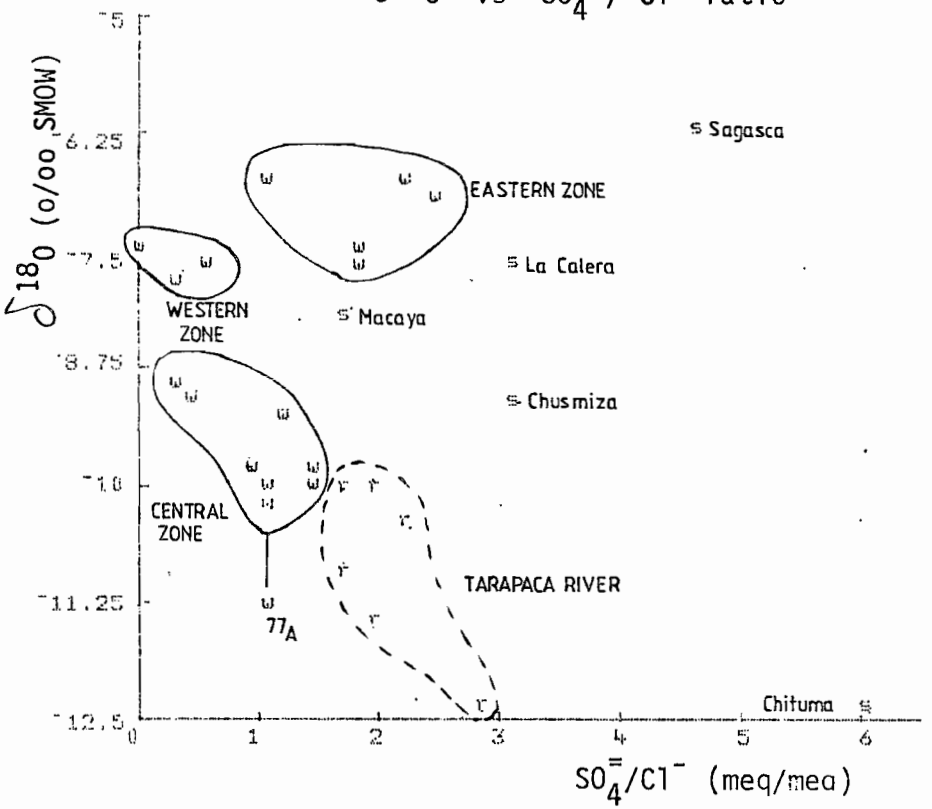


FIG. 21 B

REGION 2: GROUNDWATERS, SPRINGS AND TARAPACA RIVER

$\delta^{18}O$ vs Na^+ / K^+ ratio

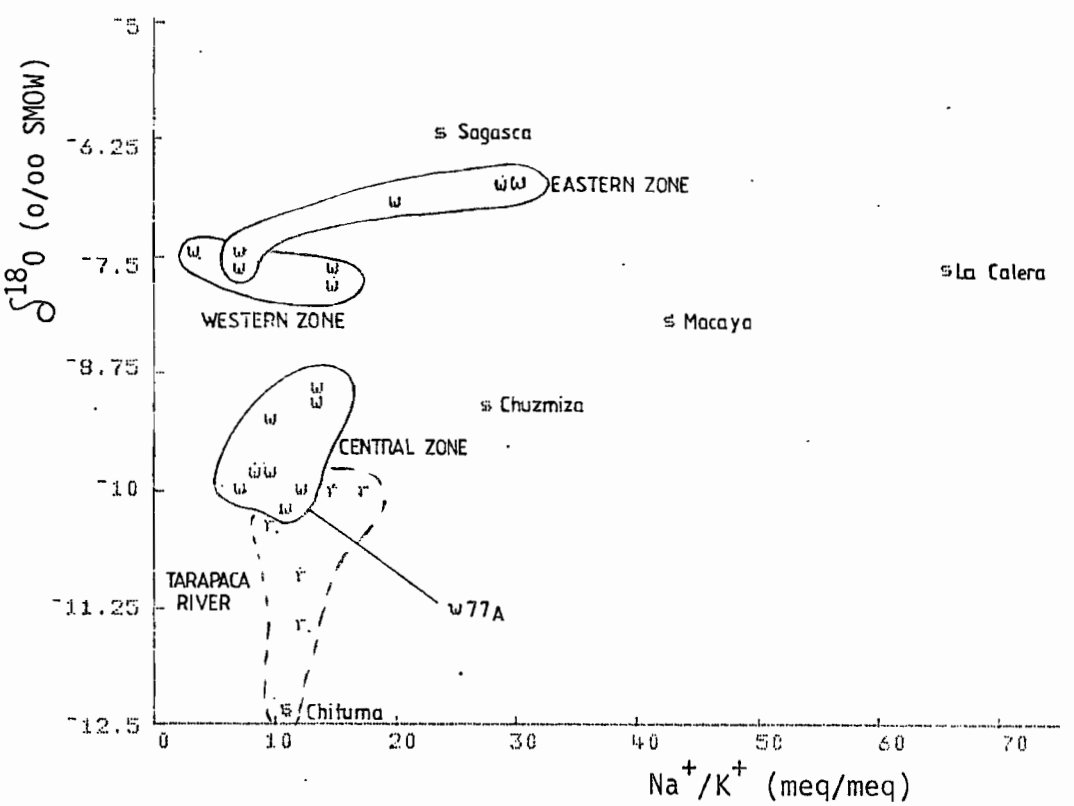


FIG. 22

REGION 3 (PICA): GROUNDWATERS AND SPRINGS

$\delta^{18}O$ vs ^{14}C content

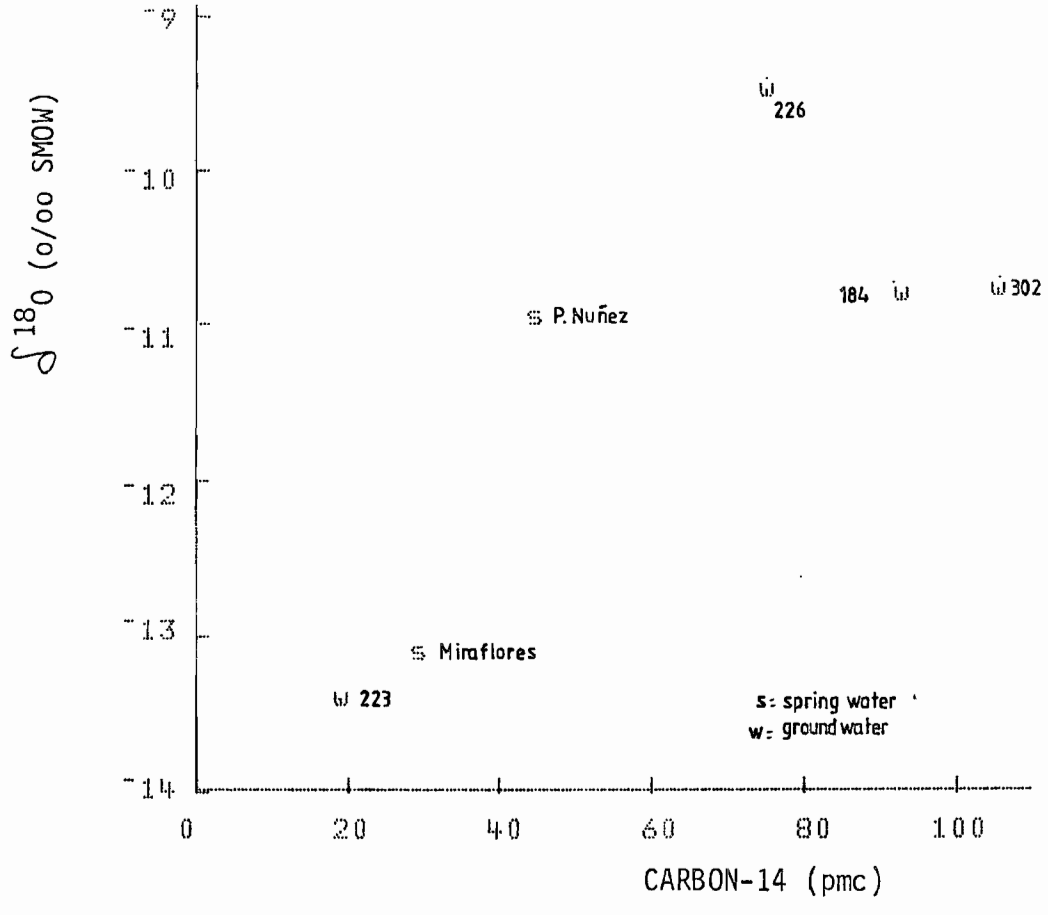


FIG. 23 A

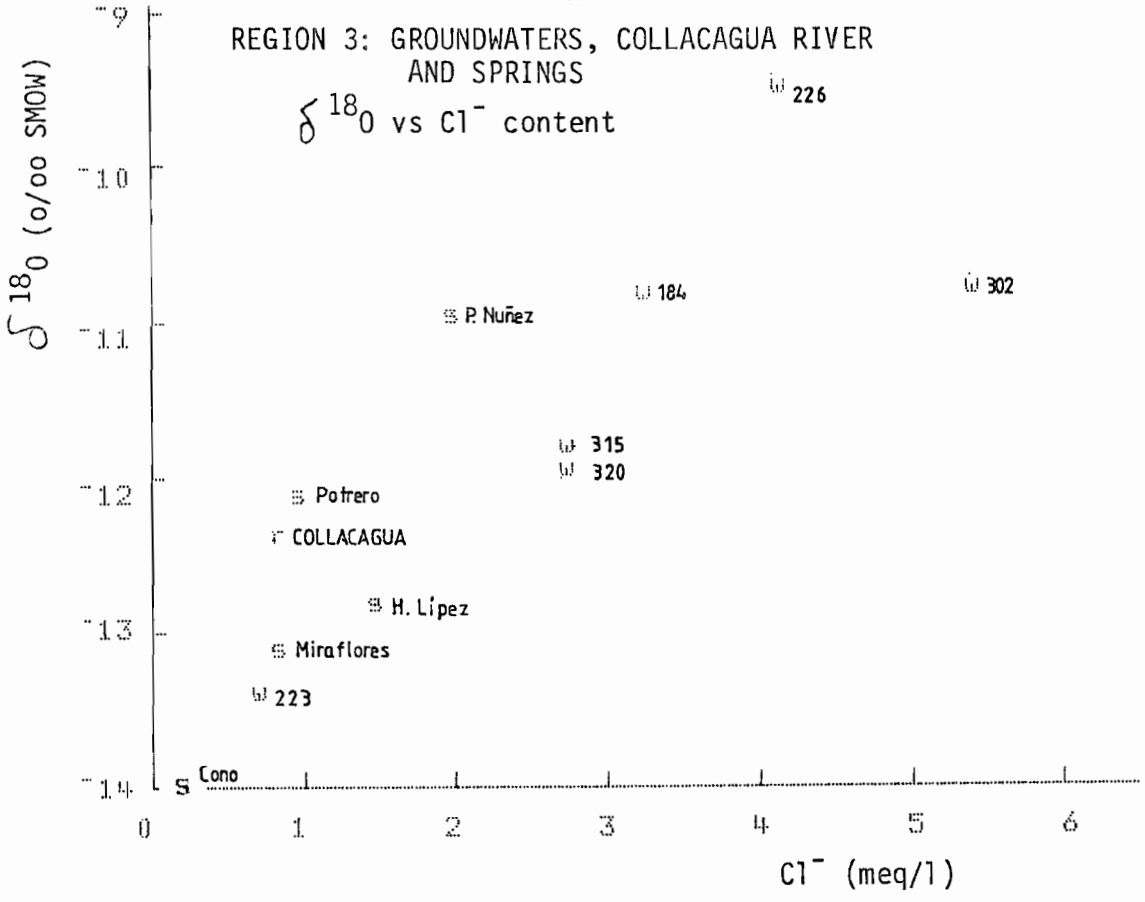


FIG. 23 B

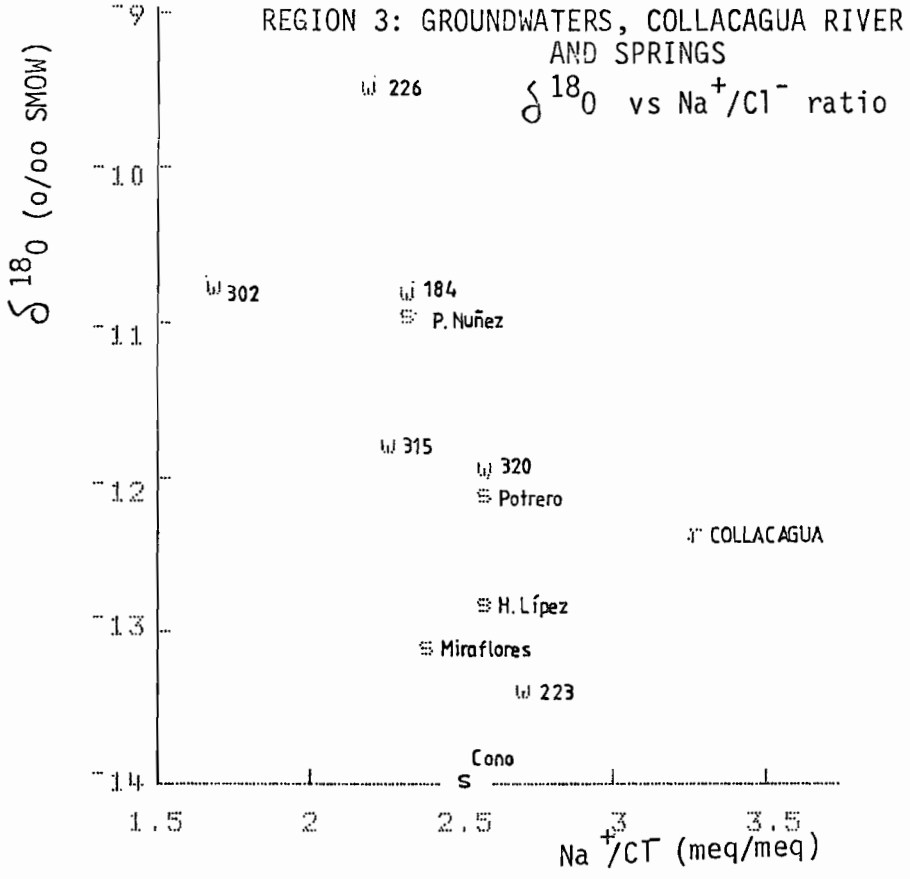


FIG. 24 A

REGION 3: GROUNDWATERS, COLLACAGUA RIVER AND SPRINGS

$\delta^{18}O$ vs $SO_4^{=}$ /Cl^- ratio

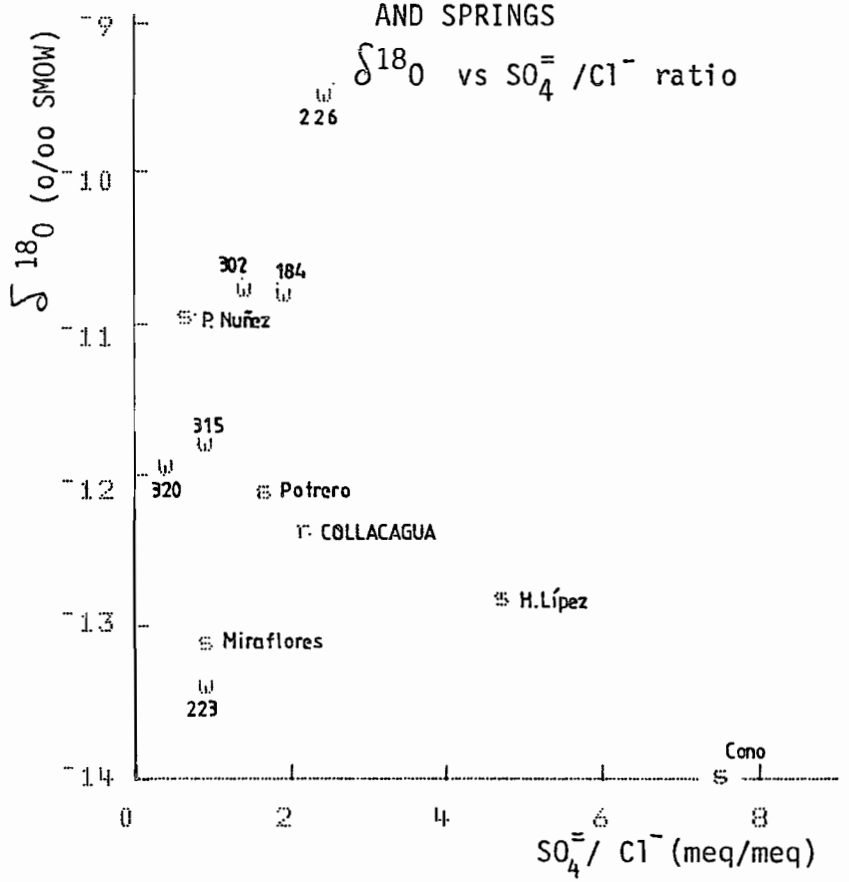


FIG. 24 B

REGION 3: GROUNDWATERS, COLLACAGUA RIVER AND SPRINGS

$\delta^{18}O$ vs Na^+/K^+ ratio

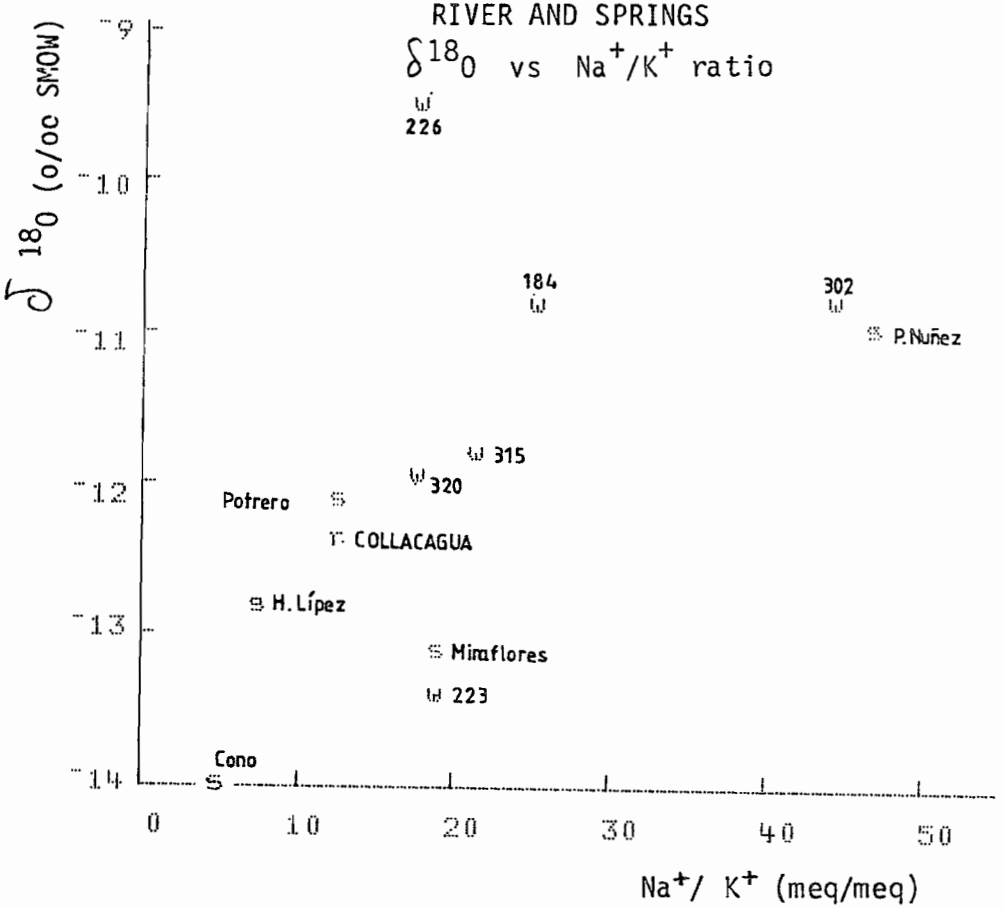


FIG. 25

REGION 4: GROUNDWATERS AND CHACARILLA RIVER

$\delta^{18}O$ vs deuterium excess parameter

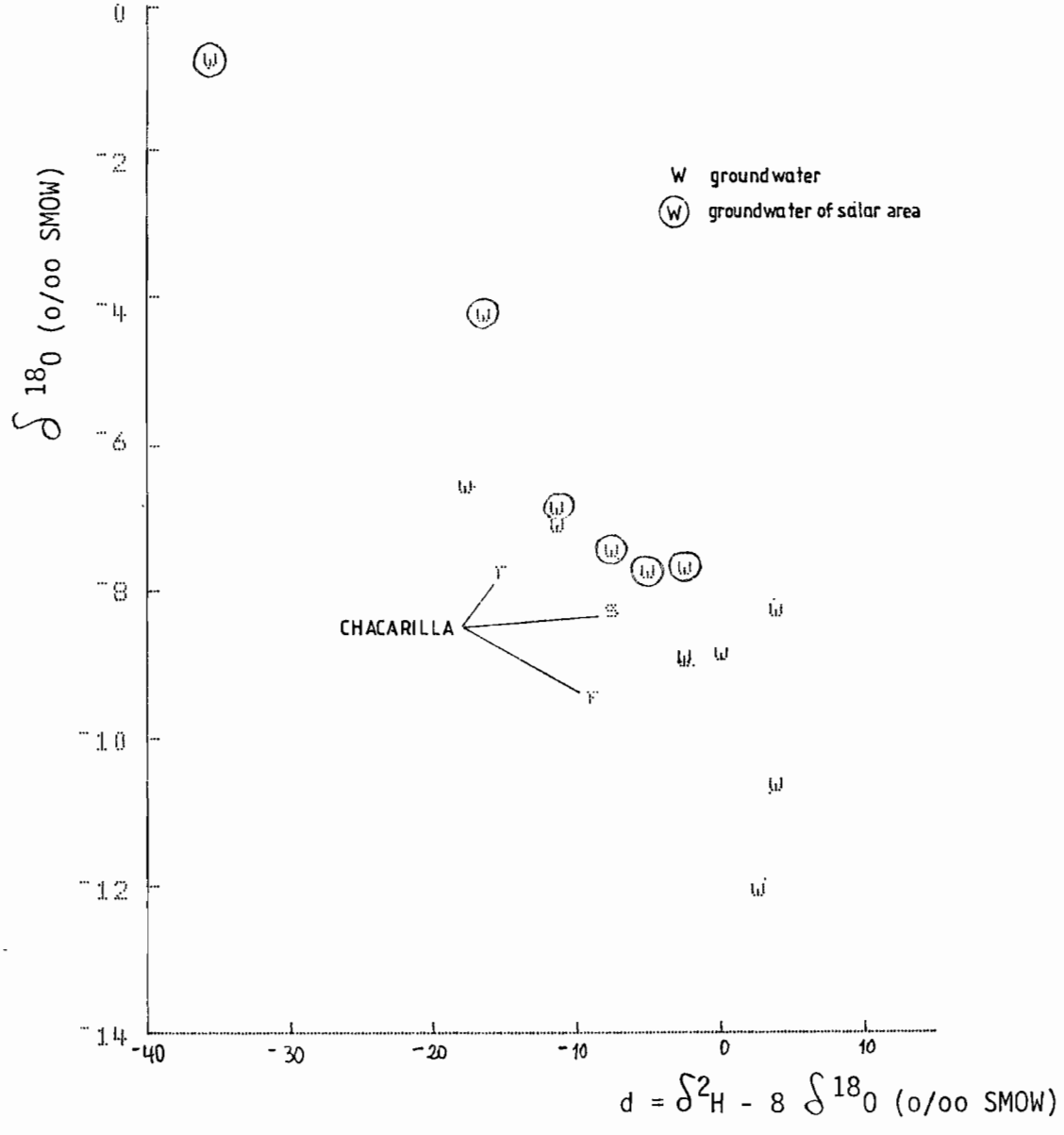


FIG. 26 A

REGION 4: GROUNDWATERS AND CHACARILLA RIVER

$\delta^{18}O$ vs Na^+/Cl^- ratio

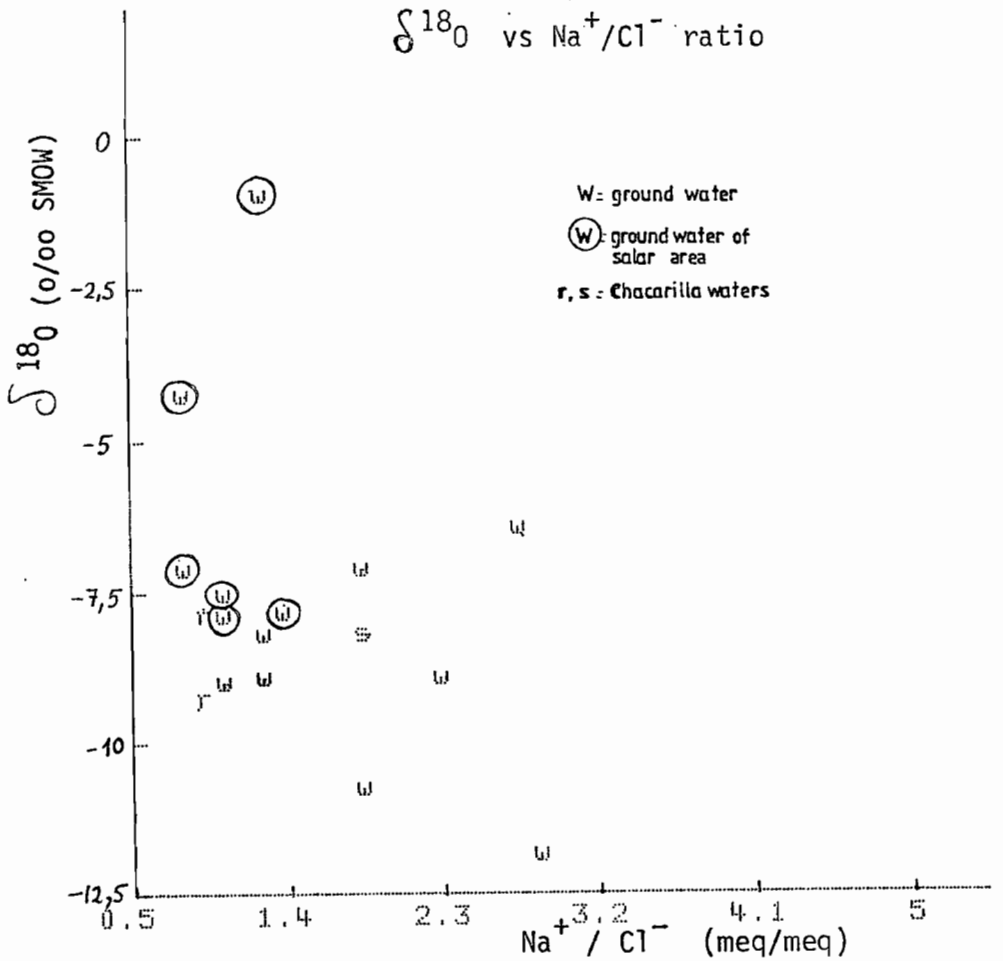


FIG. 26 B

REGION 4: GROUNDWATERS AND CHACARILLA RIVER

$\delta^{18}O$ vs $SO_4^=/Cl^-$ ratio

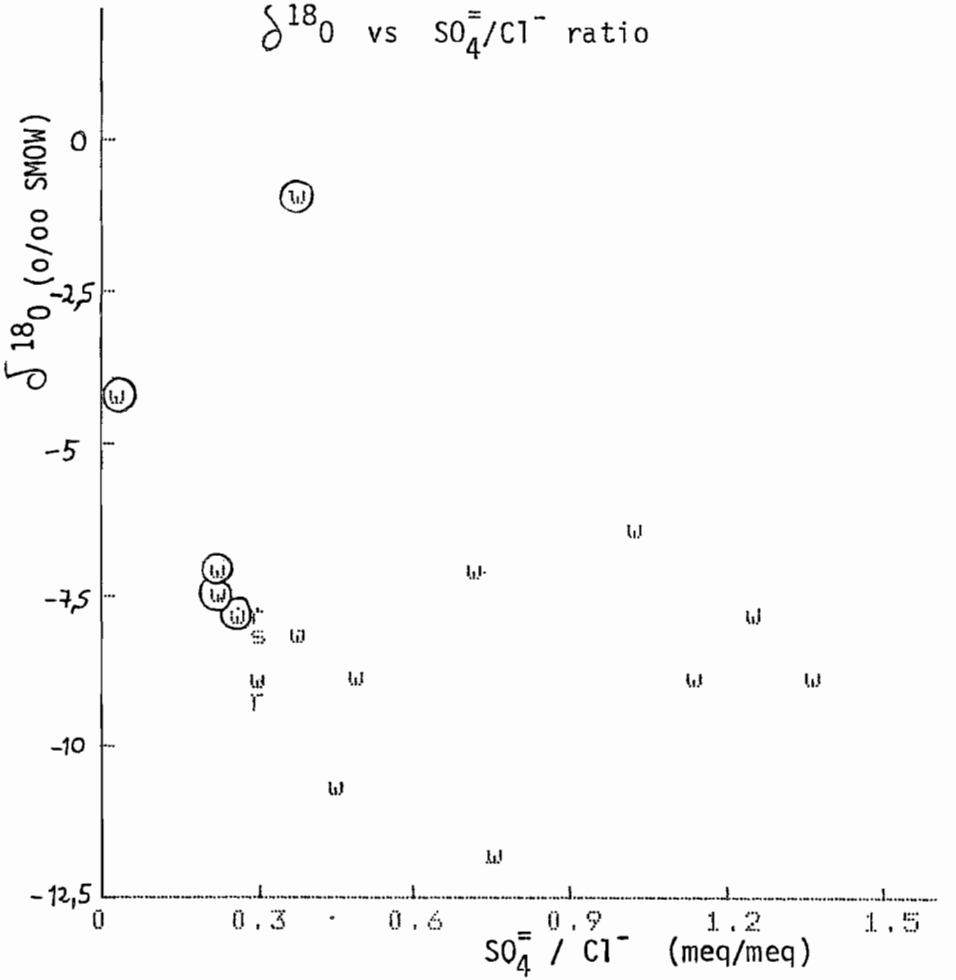
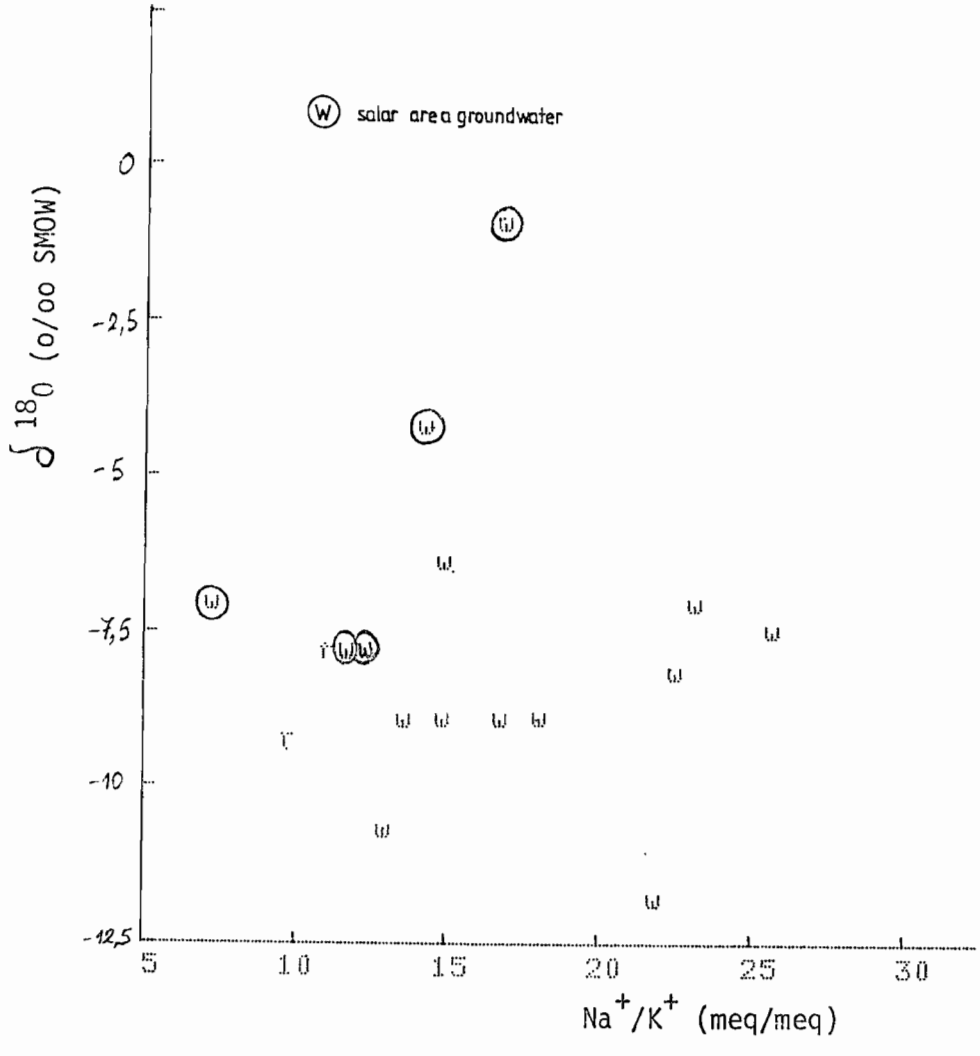


FIG. 27

REGION 4: GROUNDWATERS AND CHACARILLA RIVER

$\delta^{18}O$ vs Na^+/K^+ ratio



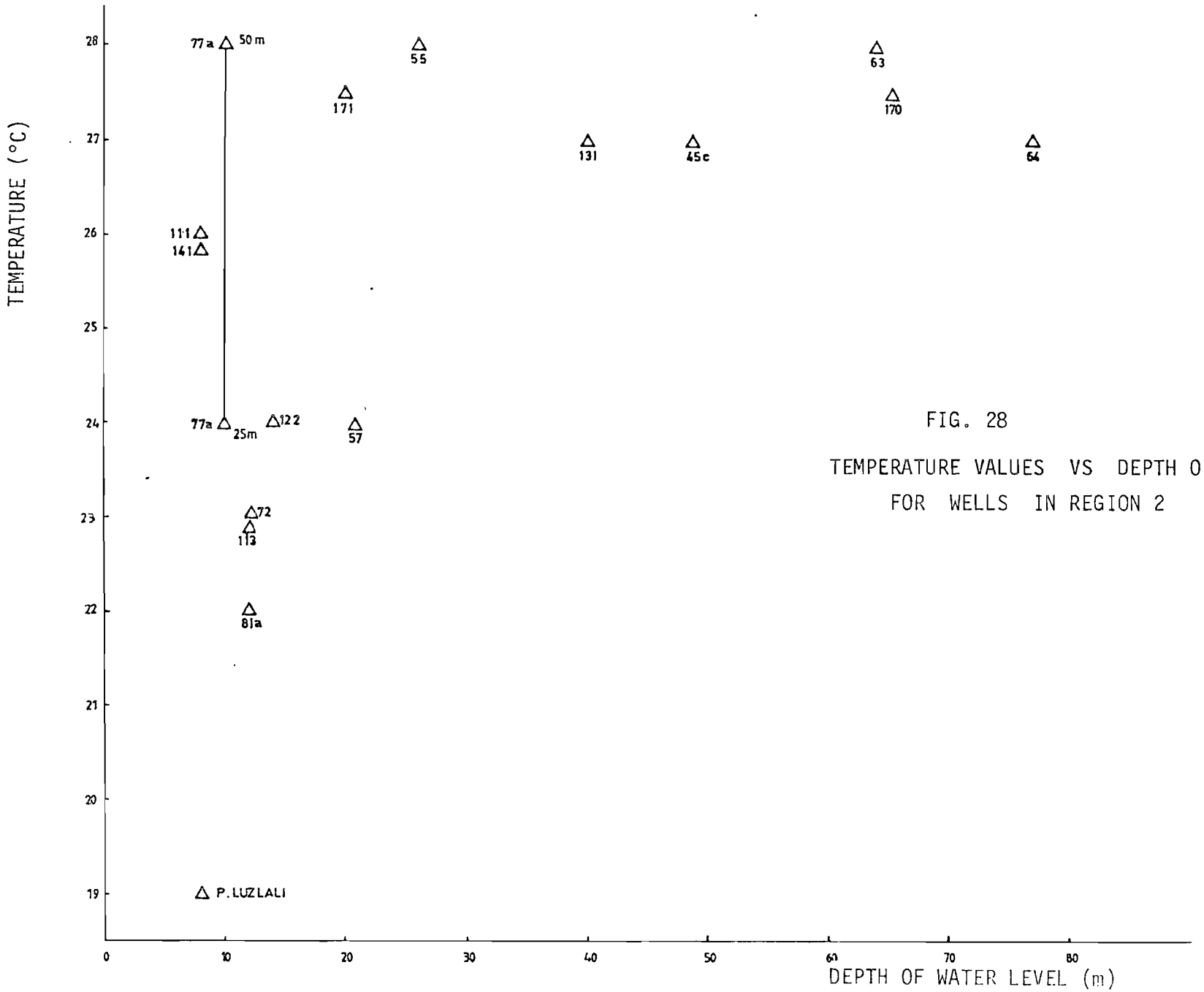
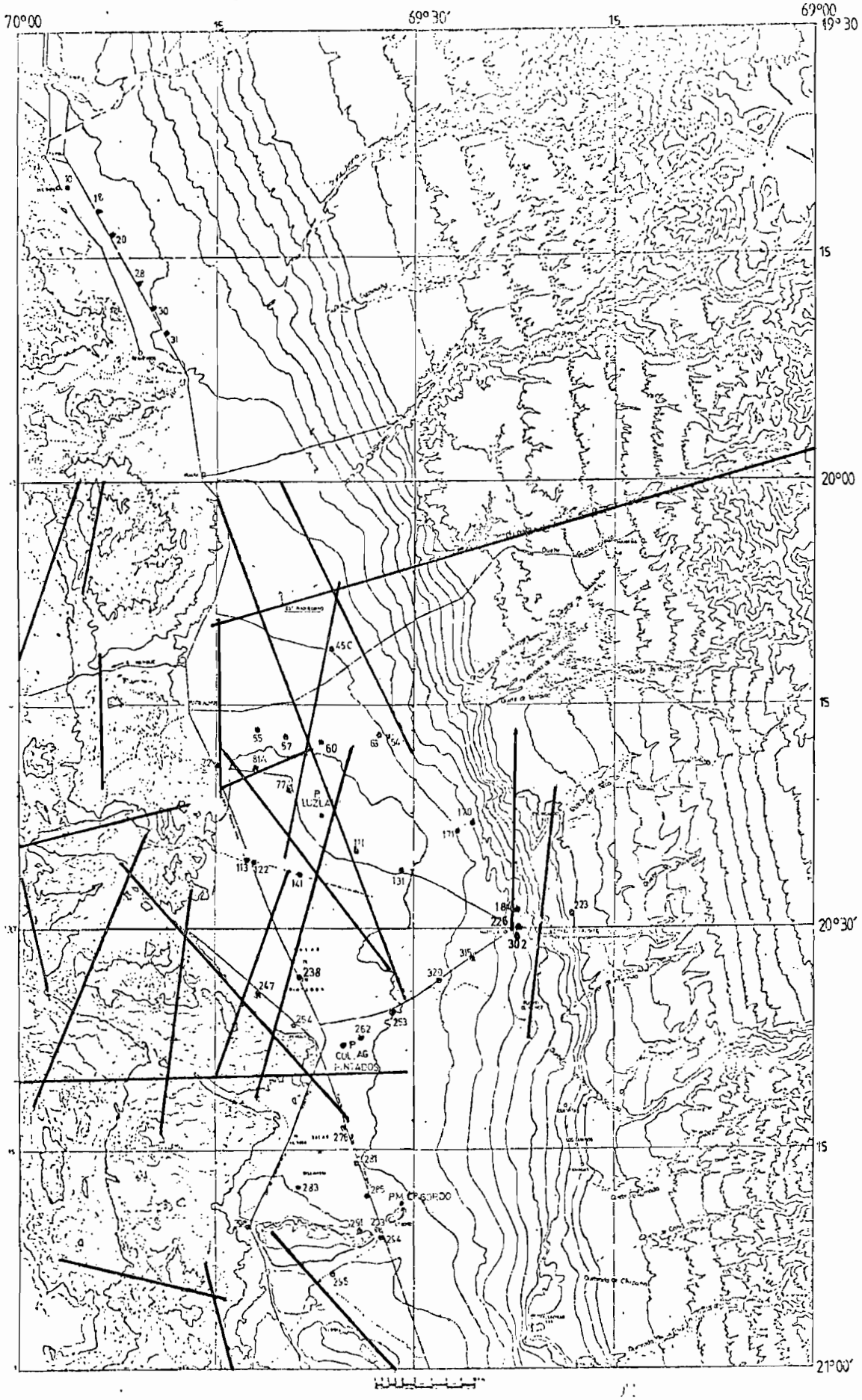


FIG. 28

TEMPERATURE VALUES VS DEPTH OF WATER LEVEL FOR WELLS IN REGION 2

FIG. 29

PRELIMINARY TECTONIC MAP OF THE UNDERLAYING BASEMENT
PAMPA DEL TAMARUGAL



BASED ON AEROMAGNETIC ANOMALY MAP OF CHILE.

UNPUBLISHED INFORMATION PROVIDED BY MR. J.C. PAPPA (SERNAGEOMIN-CHILE)

TABLES

TABLE 1

S P R I N G S	DATE	T	pH	E.C.	Na	K	Ca	Mg	Cl	SO4	HCO3	CO3	SiO2	H-2	H-3	C-13	C-14	O-18
		oC		µmhos					meq/l				mg/l	o/oo	TU	PDB	pmC	o/oo
CHICURA (AROMA BASIN)	5.1984	13.0	7.45	150	.4	.1	.7	.6	.2	.5	.88	.00	37.0	-95	.2	-11.00	99.2	-12.8
CHUSMIZA(TARAPACA BASIN)	5.1984	44.0	8.40	900	5.5	.2	1.7		1.6	5.1	.72	.20	51.0	-66	.1			-9.1
CHITUMA (TARAPACA BASIN)	5.1984	9.0	7.10	1200	4.5	.4	5.5	1.0	1.2	7.3	2.32	.00	33.0	-96	1.9	-9.00	105.9	-12.4
MACAYA (SAGASCA BASIN)	5.1984	33.0	8.10	600	4.3	.1	.7	.2	1.4	2.5	1.44	.00	38.5	-61	.4	-5.20	10.1	-8.1
SAGASCA (SAGASCA BASIN)	5.1984	22.5	7.80	2500	14.0	.6	10.7	1.2	4.4	20.5	2.00	.00	57.0	-47	.2	-11.90	85.7	-6.2
P.LA CALERA (PICA BASIN)	11.1984	31.5	7.70	2800	19.8	.3	5.0	1.4	5.9	18.3	2.10	.00	35.0	-57	.1	-10.30	47.5	-7.6
CONO (S.HUASCO B.)	5.1984	6.5	6.55	220	.5	.1	.9	.4	.2	1.5	.16	.00	36.0	-106	2.1			-14.0
POTRERO(S.DEL HUASCO B.)	5.1984	14.0	7.20	500	2.6	.2	2.3	.6	1.0	1.6	2.88	.00	37.0	-96	1.1	-5.00	46.7	-12.1
HUASCO LIPEZ (S.HUASCO)	11.1984	11.5	6.95	1100	3.9	.5	4.3	.9	1.5	7.1	1.30	.00	45.0	-98				-12.8
P.MIRAFLORES (PICA B.)	5.1984	30.0	7.95	300	1.9	.1	1.0	.1	.8	.7	1.80	.00	26.0	-103	.0	-7.00	30.0	-13.1
PUQUIO NUNEZ (PICA B.)	5.1984	23.0	8.85	600	4.7	.1	.4	.1	2.0	1.6	.96	.64	52.0	-83	.2	-8.10	43.9	-10.9
CHACARILLA (CHAC.BASIN)	11.1983		7.64	900	7.5	.1	1.3	.2	4.0	1.2	3.80	.00		-73				-8.2

R I V E R S	DATE	T	pH	E.C.	Na	K	Ca	Mg	Cl	SO4	HCO3	CO3	SiO2	H-2	H-3	C-13	C-14	O-18
		oC		µmhos					meq/l				mg/l	o/oo	TU	PDB	pmC	o/oo
AROMA R CLOSE TO PAMPA	5.1984	24.5	8.25	4100	31.2	1.9	9.0	2.0	31.3	8.5	4.80	.00	37.5	-64	1.7	-7.10	95.2	-7.1
TARAPACA AT SIBAYA	5.1984	9.0	8.35	960	5.2	.4	3.3	.9	2.7	5.3	2.08	.00	39.0	-88	1.9	-.50		-11.5
TARAPACA BEFORE COSCAYA	5.1984	13.8	8.35	1400	7.3	.6	5.5	1.4	4.4	7.6	1.68	.64	40.0	-83	1.9	-6.20		-10.8
TARAPACA AT PACHICA	5.1984	18.5	7.35	1900	10.2	.6	7.0	1.3	5.4	9.3	4.08	.00	32.5	-77	3.2			-10.0
DRAW PACHICA (TARAPACA)	5.1984	19.5	6.95	1940	10.5	.7	6.8	1.5	5.4	10.6	4.00	.00	42.0	-80	2.6	-11.80	109.5	-9.9
TARAPACA AT TARAPACA	12.1984	25.5	7.70	2000	13.8	.9	7.1	2.6	7.6	12.8	3.92	.00	43.3					
COSCAYA IN PAMPA LIRIMA	5.1984	4.5	7.75	670	3.3	.3	3.1	.6	1.6	4.6	1.36	.00	56.0	-92	1.8	-8.10		-12.4
COSCAYA BEFORE TARAPACA	5.1984	13.2	8.40	1360	6.2	.6	5.5	1.5	3.3	7.5	2.08	.80	48.0	-84	1.3	-3.90		-10.4
PIGA AT COLLACAGUA	12.1984		7.58	500	2.0	.2	1.7	1.7	.6	1.3	3.85	.00	51.2					
COLLACAGUA AT P.BLANCA	5.1984	9.0	8.00	520	2.6	.2	2.1	1.9	.8	1.8	4.00	.00	49.0	-98	1.9	-5.60		-12.4
CHACARILLA AT CHACARILLA	11.1983	23.5	7.51	7600	50.0	5.1	16.4	7.2	57.2	16.7	3.50	.00		-84				-9.4
CHACARILLA CLOSE TO PAMP	11.1983	24.0	8.03	8600	60.6	5.5	17.5	7.6	66.8	20.0	2.40	.00		-77	1.5	-3.00		-7.7

TABLE 2

WELLS	DATE	T	pH	E.C.	Na	K	Ca	Mg	Cl	SO4	HCO3	CO3	SiO2	H-2	H-3	C-13	C-14	O-18	
		oC		umhos					meq/l				mg/l	o/oo	TU	PDB	pmC	o/oo	
DGA- 10 DOLORES	5.1984	22.5	7.65	1200	6.2	1.0	4.0	1.1	6.9	4.4	.80	.00	24.0	-40	.1	-10.30		-4.9	
DGA- 18 SALAR ZAPIGA	5.1984	22.5	8.20	900	6.2	.7	2.3	.5	4.4	3.7	1.48	.00	64.0	-29				-3.8	
DGA- 20 SALAR ZAPIGA	5.1984	24.0	8.70	1000	7.1	.9	1.0	.2	3.6	3.6	.88	.80	65.0	-30				-3.7	
DGA- 28 SALAR ZAPIGA	5.1984	25.5	7.40	2800	16.9	1.7	6.7	2.0	20.1	4.8	1.68	.00	64.0	-49		-9.80		-5.3	
DGA- 30 SALAR ZAPIGA	5.1984	23.5	8.70	3000	18.2	1.8	8.8	2.3	23.2	7.1	.16	.64	58.0	-45	.3			-5.8	
DGA- 31 SALAR ZAPIGA	5.1984	23.0	8.10	3200	19.4	1.8	11.0	2.7	25.8	8.0	1.20	.00	37.6	-49		-11.50		-6.2	
DGA- 45C DUPLIJSA	5.1984	27.0	7.10	2000	8.5	.7	8.9	2.4	7.3	10.6	2.32	.00	61.0	-79	.2	-10.00	62.9	-10.0	
DGA- 55 POZO ALMONTE	12.1984	28.0	7.15	4100	18.0	1.2	14.1	4.4	26.7	10.5	1.68	.00	37.5	-67	.4	-9.00		-7.7	c
DGA- 57 LA TIRANA 1	12.1984	24.0	8.80	2100	11.1	.8	4.1	1.4	11.3	5.6	.16	.64	1.0	-72	.1			-9.0	
DGA- 60 EL CARMELO	12.1984	26.0	7.20	1100	5.1	.5	7.3	1.9	5.8	7.1	1.84	.00	49.5	-80	.4	-8.90		-9.2	
DGA- 63 MINERA SAGASCA	12.1984	28.0	7.25	1500	3.8	.5	8.3	2.2	4.5	8.5	1.60	.00	64.0	-55				-7.6	c
DGA- 64 MINERA SAGASCA	5.1984	27.0	7.30	1500	3.9	.5	8.3	1.6	4.3	8.0	2.00	.00	64.0	-56	.3	-11.30	50.6	-7.4	c
DGA- 72 PLANTA SARA	12.1984	23.0	7.40	4600	24.3	1.6	10.1	3.9	24.8	14.1	2.32	.00	54.5	-66	.4	-9.10	30.0	-7.6	c
DGA- 77A LA TIRANA 25 M	12.1984	24.0	8.05	920	4.9	.2	2.8	.2	3.1	3.5	1.68	.00	9.2	-89		-11.50	65.6	-11.2	
DGA- 77A LA TIRANA 50 M	12.1984	28.0	7.35	1800	7.4	.7	9.1	2.4	8.0	9.0	2.20	.00	50.0	-79		-8.80	59.2	-10.2	
DGA- 81A SARA-TIRANA	11.1983	22.0	8.15	3600	18.0	4.5	7.8	2.4	30.4	.1	.71	.00		-66				-7.5	c
DGA-111 LA HUAICA RADIO	12.1984	26.0	7.15	2000	7.0	.9	8.9	2.3	8.8	9.6	1.20	.00	27.6	-76	.0	-11.90		-10.0	
DGA-113 REFRESCO	12.1984	23.0	7.30	3400	15.8	1.2	10.0	4.1	22.3	6.5	1.60	.00	74.0	64	.0	-10.20	14.3	-8.9	c
DGA-122 REFRESCO	12.1984	24.0	8.40	3600	20.0	1.6	7.9	3.2	31.0	.9	.60	.20	1.4						
DGA-S/N PIQUE LUZLALI	12.1984	19.0	7.55	1600	6.0	.7	7.3	2.1	5.9	8.5	1.68	.00	44.5	-78	.0	-11.90	42.1	-9.7	
DGA-131 CANCHONES E	5.1984	27.0	7.55	950	5.9	.3	2.1	.4	2.0	5.0	1.92	.00	62.5	-53	.0	-11.40	17.1	-6.9	c
DGA-141 HISPANIA 20 M	12.1984	26.0	7.10	1900	8.4	.9	10.3	3.6	10.8	10.2	2.24	.00	69.0	-75		-10.10	54.1	-9.7	
DGA-141 HISPANIA 70 M	12.1984	26.0	7.10	1900	8.4	.9	10.3	3.6	10.8	10.2	2.24	.00	69.0	-77		-10.90	53.3	-9.8	
DGA-170 LA CALERA 3	5.1984	27.5	7.55	950	17.1	.6	4.3	.8	6.7	14.7	1.44	.00	60.0	-49	.1			-6.7	c
DGA-171 LA CALERA 2	12.1984	27.5	8.60	2000	17.4	.6	1.4	.9	8.6	9.7	1.20	.80	4.0	-49				-6.6	c
DGA-184 ESMERALDA 13	5.1984	25.5	7.30	1300	7.5	.3	4.0	.5	3.2	5.9	3.52	.00		-85	.3	-12.80	92.3	-10.7	
DGA-223 CONCOVA 1	12.1984	31.0	7.75	300	1.9	.1	1.1	.1	.7	.7	1.76	.00	31.0	-104	.1	-8.20	24.5	-13.4	
DGA-226 CERVELLINO	5.1984	34.0	7.60	1650	9.1	.5	6.2	.4	4.1	10.5	1.36	.00	48.5	-76	.4	-12.60	76.5	-9.4	
DGA-302 MATILLA 5	5.1984	24.5	6.80	1700	9.0	.2	5.8	.6	5.4	7.5	3.12	.00	49.5	-88	.1	-11.80	105.3	-10.7	
DGA-315 PINTADOS-PICA 3	5.1984	30.0	7.55	1050	6.3	.3	1.4	.3	2.8	2.3	3.04	.00	24.0	-95	.0	-11.60		-11.8	
DGA-320 PINTADOS-PICA 2	5.1984	28.5	10.20	1000	7.0	.4	.2	.1	2.7	1.0	.16	3.68	.6	-96	.0	-9.00		-12.0	
DGA-238 PINTADOS RADIOI	5.1984	24.0	6.95	28000	241.5	9.3	40.0	15.0	244.8	57.2	2.24	.00	72.0	-67	.0			-7.5	
DGA-242 SALAR PINTADOS	5.1984	23.5	10.50	6100	38.3	3.2	20.9	3.9	27.8	35.2	.00	.96	69.6	-64		-7.80		-7.7	
DGA-253 PINTADOS PICA 1	5.1984	25.0	8.55	1100	8.8	.4	.2	.1	3.1	2.3	3.76	.64	5.8	-92	.3	-10.80		-11.9	
DGA-254 SALAR PINTADOS	5.1984	25.0	11.10	105000	1053.3	72.4	224.2	41.1	1278.5	40.6	.00	1.92	2.0	-50		-11.00		-4.2	
DGA-262 COL.AG.PINTADOS	12.1984	28.2	7.75	2000	14.4	.8	1.2	.3	6.2	7.0	3.68	.00	64.0	-71		-6.40	<5.0	-8.9	
DGA-267 SALAR BELLAVIST	5.1984	22.5	11.00	20500	132.8	11.0	21.8		128.2	33.5	.00	1.28	24.0	-67				-7.7	
DGA-276 SALAR BELLAVIST	11.1983	21.5	7.85	800	6.1	.4	.8	.2	2.2	2.3	2.84	.00	-1.0	-69				-6.5	
DGA-281 SALAR BELLAVIST	5.1984	23.0	8.90	1200	9.2	.4	1.3	.5	5.0	3.7	.80	1.28	45.0	-68		-5.70		-7.1	
DGA-283 SALAR BELLAVIST	5.1984	23.0	8.70	19000	125.9	17.4	43.1	18.9	161.8	38.5	.00	1.44	43.0	67		-6.00		-6.9	
DGA-286 SALAR BELLAVIST	5.1984	24.0	8.95	1500	11.2	.5	1.4	.3	8.7	3.3	.72	.80	46.0	-61				-8.1	
DGA-290 SALAR BELLAVIST	5.1984	23.0	9.05	90000	1060.0	63.4	37.5	38.0	880.5	318.0	.00	5.92	1.7	-42				-.8	
DGA-291 SALAR BELLAVIST	1.1984	22.0	7.92	73000	782.0	134.5	36.0	32.0	625.1	296.0	3.65	.00							
DGA-293 CHALLACOLLO 1	5.1984	24.5	6.70	1800	11.6	.7	3.1	.8	9.2	4.4	2.16	.00	50.0	-74	.1	-6.70		-8.9	
DGA-294 SALAR BELLAVIST	5.1984	24.5	11.00	4200	23.5	1.6	20.5	1.3	19.0	25.8	.00	.48	10.0	-74				-8.9	
DGA-296 SALAR SUR VIEJO	5.1984	25.5	7.95	19000	136.0	5.5	35.2	10.8	140.1	51.0	1.53	.00	61.0						
DGA-S/N P.COL.PINTADOS	11.1983	18.0	6.85	800	5.2	.4	1.3	.6	2.8	1.3	3.25	.00		-82			46.8	-10.7	
DGA-S/N POZO M.C.GORDO	12.1984	27.0	7.75	2100	12.2	.9	2.9	1.6	11.6	3.6	2.32	.00	64.0	-73		-6.00	12.0	-8.9	

TABLE 3

S P R I N G S	E.C. umhos	O-18 o/oo	Na/Cl	Na/K	SO4/Cl meq/meq	Ca/SO4	Ca/Mg	d o/oo	Cat-An meq/lt	ERROR meq/meq
+ CHICURA (AROMA BASIN)	150	-12.8	2.00	4.00	2.50	1.40	1.17	7.4	.22	.065
CHUSMIZA(TARAPACA BASIN)	900	-9.1	3.44	27.50	3.19	.33		6.8		
+ CHITUMA (TARAPACA BASIN)	1200	-12.4	3.75	11.25	6.08	.75	5.50	3.2	.58	.026
MACAYA (SAGASCA BASIN)	600	-8.1	3.07	43.00	1.79	.28	3.50	3.8	-.04	-.004
• SAGASCA (SAGASCA BASIN)	2500	-6.2	3.18	23.33	4.66	.52	8.92	2.6	-.40	-.007
• P.LA CALERA (PICA BASIN)	2800	-7.6	3.36	66.00	3.10	.27	3.57	3.8	.20	.004
+ CONO (S.HUASCO B.)	220	-14.0	2.50	5.00	7.50	.60	2.25	6.0	.04	.011
+ POTRERO(S.DEL HUASCO B.)	500	-12.1	2.60	13.00	1.60	1.44	3.83	.8	.22	.020
+ HUASCO LIPEZ (S.HUASCO)	1100	-12.8	2.60	7.80	4.73	.61	4.78	4.4	-.30	-.015
• P.MIRAFLORES (PICA B.)	300	-13.1	2.37	19.00	.87	1.43	10.00	1.8	-.20	-.031
• PUQUIO NUNEZ (PICA B.)	600	-10.9	2.35	47.00	.80	.25	4.00	4.2	.10	.010
• CHACARILLA (CHAC.BASIN)	900	-8.2	1.88	75.00	.30	1.08	6.50	-7.4	.10	.006

R I V E R S	E.C. umhos	O-18 o/oo	Na/Cl	Na/K	SO4/Cl meq/meq	Ca/SO4	Ca/Mg	d o/oo	Cat-An meq/lt	ERROR meq/meq
AROMA R CLOSE TO PAMPA	4100	-7.1	1.00	16.42	.27	1.06	4.50	-7.2	-.50	-.006
TARAPACA AT SIBAYA	960	-11.5	1.93	13.00	1.96	.62	3.67	4.0	-.28	-.014
TARAPACA BEFORE COSCAYA	1400	-10.8	1.66	12.17	1.73	.72	3.93	3.4	.48	.016
TARAPACA AT PACHICA	1900	-10.0	1.89	17.00	1.72	.75	5.38	3.0	.32	.008
DRAW PACHICA (TARAPACA)	1940	-9.9	1.94	15.00	1.96	.64	4.53	-.8	-.50	-.013
TARAPACA AT TARAPACA	2000		1.82	15.33	1.68	.55	2.73		.08	.002
COSCAYA IN PAMPA LIRIMA	670	-12.4	2.06	11.00	2.87	.67	5.17	7.2	-.26	-.017
COSCAYA BEFORE TARAPACA	1360	-10.4	1.88	10.33	2.27	.73	3.67	-.8	.12	.004
PIGA AT COLLACAGUA	500		3.33	10.00	2.17	1.31	1.00		-.15	-.013
COLLACAGUA AT P.BLANCA	520	-12.4	3.25	13.00	2.25	1.17	1.11	1.2	.20	.015
CHACARILLA AT CHACARILLA	7600	-9.4	.87	9.80	.29	.98	2.28	-8.8	1.30	.008
CHACARILLA CLOSE TO PAMP	8600	-7.7	.91	11.02	.30	.88	2.30	-15.4	2.00	.011

NOTE : $d = \delta^{2}H - 8\,\delta^{18}O$

ERROR=(CATIONS - ANIONS) / (CATIONS + ANIONS)

TABLE 4

WELLS		E.C. umhos	O-18 o/oo	Na/Cl	Na/K	SO4/Cl meq/meq	Ca/SO4	Ca/Mg	d o/oo	Cat-An meq/lt	ERROR meq/meq
DGA- 10	DOLORES	1200	-4.9	.90	6.20	.64	.91	3.64	-.8	.20	.008
DGA- 18	SALAR ZAPIGA	900	-3.8	1.41	8.86	.84	.62	4.60	1.4	.12	.006
DGA- 20	SALAR ZAPIGA	1000	-3.7	1.97	7.89	1.00	.28	5.00	-.4	.32	.018
DGA- 28	SALAR ZAPIGA	2800	-5.3	.84	9.96	.24	1.40	3.35	-6.6	.76	.014
DGA- 30	SALAR ZAPIGA	3000	-5.8	.78	10.11	.31	1.24	3.83	1.4	.00	.000
DGA- 31	SALAR ZAPIGA	3200	-6.2	.75	10.54	.31	1.38	4.07	.6	-.06	-.001
DGA- 45C	DUPLIJSA	2000	-10.0	1.16	12.14	1.45	.84	3.71	1.0	.28	.007
DGA- 55	POZO ALMONTE	4100	-7.7	.67	15.00	.39	1.34	3.20	-5.4	-1.18	-.015
DGA- 57	LA TIRANA 1	2100	-9.0	.98	13.88	.50	.73	2.93	.0	-.30	-.009
DGA- 60	EL CARMELO	1100	-9.2	.88	10.20	1.22	1.03	3.84	-6.4	.06	.002
DGA- 63	MINERA SAGASCA	1500	-7.6	.84	7.60	1.89	.98	3.77	5.8	.20	.007
DGA- 64	MINERA SAGASCA	1500	-7.4	.91	7.80	1.86	1.04	5.19	3.2	.00	.000
DGA- 72	PLANTA SARA	4600	-7.6	.98	15.19	.57	.72	2.59	-5.2	-1.32	-.016
DGA- 77A	LA TIRANA 25 M	920	-11.2	1.58	24.50	1.13	.80	14.00	.6	-.18	-.011
DGA- 77A	LA TIRANA 50 M	1800	-10.2	.92	10.57	1.13	1.01	3.79	2.6	.40	.010
DGA- 81A	SARA-TIRANA	3600	-7.5	.59	4.00	.00	60.00	3.25	-6.0	1.46	.023
DGA-111	LA HUAICA RADIO	2000	-10.0	.80	7.78	1.09	.93	3.87	4.0	-.50	-.013
DGA-113	REFRESCO	3400	-8.9	.71	13.17	.29	1.54	2.44	7.2	.70	.011
DGA-122	REFRESCO	3600		.65	12.50	.03	8.78	2.47		.00	.000
DGA-S/N	PIQUE LUZLALI	1600	-9.7	1.02	8.57	1.44	.86	3.48	-.4	.02	.001
DGA-131	CANCHONES E	950	-6.9	2.95	19.67	2.50	.42	5.25	2.2	-.22	-.012
DGA-141	HISPANIA 20 M	1900	-9.7	.78	9.33	.94	1.01	2.86	2.6	-.04	-.001
DGA-141	HISPANIA 70 M	1900	-9.8	.78	9.33	.94	1.01	2.86	1.4	-.04	-.001
DGA-170	LA CALERA 3	950	-6.7	2.55	28.50	2.19	.29	5.38	4.6	-.04	-.001
DGA-171	LA CALERA 2	2000	-6.6	2.02	29.00	1.13	.14	1.56	3.8	.00	.000
DGA-184	ESMERALDA 13	1300	-10.7	2.34	25.00	1.84	.68	8.00	.6	-.32	-.013
DGA-223	CONCOVA 1	300	-13.4	2.71	19.00	1.00	1.57	11.00	3.2	.04	.006
DGA-226	CERVELLINO	1650	-9.4	2.22	18.20	2.56	.59	15.50	-.8	.24	.007
DGA-302	MATILLA 5	1700	-10.7	1.67	45.00	1.39	.77	9.67	-2.4	-.42	-.013
DGA-315	PINTADOS-PICA 3	1050	-11.8	2.25	21.00	.82	.61	4.67	-.6	.16	.010
DGA-320	PINTADOS-PICA 2	1000	-12.0	2.59	17.50	.37	.20	2.00	.0	.16	.010
DGA-238	PINTADOS RADIOI	28000	-7.5	.99	25.97	.23	.70	2.67	-7.0	1.56	.003
DGA-242	SALAR PINTADOS	6100	-7.7	1.38	11.97	1.27	.59	5.36	-2.4	2.34	.018
DGA-253	PINTADOS PICA 1	1100	-11.9	2.84	22.00	.74	.09	2.00	3.2	-.30	-.016
DGA-254	SALAR PINTADOS	105000	-4.2	.82	14.55	.03	5.52	5.45	-16.4	69.98	.026
DGA-262	COL.AG.PINTADOS	2000	-8.9	2.32	18.00	1.13	.17	4.00	.2	-.18	-.005
DGA-267	SALAR BELLAVIST	20500	-7.7	1.04	12.07	.26	.65		-5.4		
DGA-276	SALAR BELLAVIST	800	-6.5	2.77	15.25	1.05	.35	4.00	-17.0	.16	.011
DGA-281	SALAR BELLAVIST	1200	-7.1	1.84	23.00	.74	.35	2.60	-11.2	.62	.028
DGA-283	SALAR BELLAVIST	19000	-6.9	.78	7.24	.24	1.12	2.28	-11.8	3.56	.009
DGA-286	SALAR BELLAVIST	1500	-8.1	1.29	22.40	.38	.42	4.67	3.8	-.12	-.004
DGA-290	SALAR BELLAVIST	90000	-.8	1.20	16.72	.36	.12	.99	-35.6	-5.52	-.002
DGA-291	SALAR BELLAVIST	73000		1.25	5.81	.47	.12	1.13		59.75	.031
DGA-293	CHALLACOLLO 1	1800	-8.9	1.26	16.57	.48	.70	3.88	-2.8	.44	.014
DGA-294	SALAR BELLAVIST	4200	-8.9	1.24	14.69	1.36	.79	15.77	-2.8	1.62	.018
DGA-296	SALAR SUR VIEJO	19000		.97	24.73	.36	.69	3.26		-5.13	-.013
DGA-S/N	P.COL.PINTADOS	800	-10.7	1.86	13.00	.46	1.00	2.17	3.6	.15	.010
DGA-S/N	POZO M.C.GORDO	2100	-8.9	1.05	13.56	.31	.81	1.81	-1.8	.08	.002

NOTE : $d = \delta^{2}H - 8\,\delta^{18}O$

ERROR=(CATIONS - ANIONS) / (CATIONS + ANIONS)

TABLE 5

TARAPACA RIVER AT PACHICA (FLOODS)

DAY 1985	E.C. µmhos	HCO3	Cl	SO4	Ca	Mg	K	Na	SiO2	Na/Cl	SO4/Cl	Na/k	SYMBOL IN FIGURE
				meq/l					mg/l		meq/meq		
13.81	1902	3.02	5.55	10.07	5.45	2.15	.73	10.84	55.60	1.9532	1.8144	14.8493	A
14.81	1876	3.17	5.71	9.30	5.58	1.90	.71	10.60	57.20	1.8564	1.6287	14.9296	B
15.35	1770	3.20	5.34	10.20	6.00	2.50	.69	9.20		1.7228	1.9101	13.3333	C
15.81	1814	2.91	5.45	10.20	5.75	2.25	.71	9.70		1.7798	1.8716	13.6620	D
16.33	1792	3.30	5.18	10.25	6.50	2.00	.69	9.00		1.7375	1.9788	13.0435	E
16.38	1792	3.16	5.29	10.10	6.50	2.00	.69	9.10		1.7202	1.9093	13.1884	F
16.42	1792	3.01	5.34	10.20	6.00	2.50	.69	9.20		1.7228	1.9101	13.3333	G
16.46	1792	3.01	5.40	10.70	6.00	2.50	.71	9.80		1.8148	1.9815	13.8028	H
16.81	1748	2.62	5.40	9.85	5.50	2.50	.70	9.40		1.7407	1.8241	13.4286	J
17.31	1792	3.30	5.34	10.30	6.50	2.50	.70	9.10		1.7041	1.9288	13.0000	J
17.81	1792	2.62	5.61	10.30	5.25	2.75	.71	9.80		1.7469	1.8360	13.8028	K
51.35	1255	3.17	3.06	5.90	4.98	1.15	.55	5.84	46.20	1.9085	1.9281	10.6182	L
52.35	1058	2.97	3.01	5.56	4.53	1.05	.51	5.84	49.60	1.9402	1.8472	11.4510	M
52.81	1128	3.22	2.54	5.10	4.63	1.05	.50	5.04	44.00	1.9843	2.0079	10.0800	N
52.98	1118	3.07	2.54	5.10	4.48	1.00	.50	5.04	45.60	1.9843	2.0079	10.0800	O
53.33	980	3.07	2.60	5.06	4.33	.93	.49	5.20	46.20	2.0000	1.9462	10.6122	P
53.50	975	2.74	2.65	5.10	4.13	.90	.51	5.20	49.60	1.9623	1.9245	10.1961	Q
53.67	1137	2.77	2.68	4.90	4.08	.95	.50	5.20	44.00	1.9403	1.8284	10. 000	R
54.33	1230	4.01	2.80	5.78	5.83	1.15	.51	5.54	45.60	1.9786	2.0643	10.8627	S
54.67	1065								35.00				T
55.00	1034	2.57	2.33	4.71	4.08	.75	.47	4.58	38.60	1.9657	2.0215	9.7447	U
55.33									37.80				V
55.50	947	3.37	2.02	4.66	4.86	.87	.50	4.22	36.40	2.0891	2.3069	8.4400	W
55.67									39.20				X
55.92	1025	2.77	2.33	5.42	4.51	1.00	.50	4.78	49.00	2.0515	2.3262	9.5600	Y
56.50	1025	3.20	2.38	5.26	4.70	.90	.51	4.84	50.75	2.0336	2.2101	9.4902	Z
56.83	1020	2.82	2.49	5.34	4.31	1.00	.51	4.98	53.50	2.0000	2.1446	9.7647	a
57.33	1037	3.01	2.49	5.32	4.41	.95	.49	4.98	53.50	2.0000	2.1365	10.1633	b
58.33	1001	2.43	2.88	5.44	4.02	.85	.56	5.12	54.25	1.7778	1.8889	9.1429	c
58.33	1127	3.01	2.86	5.35	4.41	1.10	.55	5.69	60.25	1.9895	1.8706	10.3455	d
66.33	1110	2.86	2.86	5.55	4.31	.95	.51	5.69	52.00	1.9895	1.9406	11.1569	e
67.33	1168	3.06	3.07	5.56	4.36	1.20	.51	6.00	56.00	1.9544	1.8111	11.7647	f
67.75	1216	3.01	3.17	5.92	4.51	1.25	.57	6.16	56.00	1.9432	1.8675	10.8070	g
68.42	900	2.91	1.85	4.61	4.38	.80	.46	4.00	42.00	2.1622	2.4919	8.6957	h
68.58	863	2.57	1.90	4.35	3.77	.75	.45	3.94	42.75	2.0737	2.2895	8.7556	i
68.75	887	2.18	2.12	4.51	3.44	.70	.47	4.34	44.75	2.0472	2.1274	9.2340	j
69.50	930	2.43	2.33	4.73	3.48	1.10	.46	4.52	48.25	1.9399	2.0300	9.8261	k
70.33	1010	2.43	2.59	4.98	3.68	1.05	.47	4.98	53.50	1.9228	1.9228	10.5957	l
71.33	1050	2.67	2.75	5.32	3.92	1.00	.49	5.32	51.50	1.9345	1.9345	10.8571	m

TABLE 6

AROMA RIVER AT ARIQUILDA (FLOODS)

DAY 1985	E.C. µmhos	HCO3	Cl	SO4	Ca	Mg	K	Na	SiO2	Na/Cl	SO4/Cl	Na/K	SYMBOL IN FIGURE
				meq/l					mg/l		meq/meq		
4.33	4513	3.61	29.06	7.30	6.86	1.20	2.47	29.20	76.50	1.0048	.2512	11.8219	A
5.33	4580	3.61	29.06	7.30	7.06	1.20	2.47	29.60	77.50	1.0186	.2512	11.9838	B
16.33	4005	3.74	27.29	8.90	6.86	1.40	2.50	30.00		1.0993	.3261	12.0000	C
17.38	4005	3.69	27.80	8.65	6.86	1.50	2.54	30.00		1.0791	.3112	11.8110	D
17.46	4071	3.69	27.55	8.65	6.76	1.40	2.58	30.00		1.0889	.3140	11.6279	E
17.83	4093	3.69	28.31	8.85	6.76	1.30	2.65	30.80		1.0880	.3126	11.6226	F
18.33	4082	3.69	27.29	8.40	6.66	1.20	2.56	30.00		1.0993	.3078	11.7187	G
18.83	4160	3.74	28.31	8.90	6.86	1.30	2.65	30.00		1.0597	.3144	11.3208	H
34.33	4104	3.76	29.06	7.30	6.86	1.50	2.42	30.40	75.80	1.0461	.2512	12.5620	I
35.83	4104	3.66	28.54	7.00	6.86	1.10	2.47	29.20	76.75	1.0231	.2453	11.8219	J
37.83	4165	3.61	29.58	7.80	6.86	1.20	2.52	29.60	78.00	1.0007	.2637	11.7460	K
38.33	4536	3.61	29.58	8.10	6.86	1.00	2.47	30.40	77.00	1.0277	.2738	12.3077	L
39.33	4193	3.61	29.58	8.15	6.86	1.00	2.58	31.20	78.00	1.0548	.2755	12.0930	M
40.33	4027	3.61	29.58	7.20	6.96	1.20	2.40	29.60	77.00	1.0007	.2434	12.3333	N
41.33	4185	6.11	28.03	9.00	7.06	2.00	2.58	30.80	77.00	1.0988	.3211	11.9380	O
43.33	3760								71.75				P
44.33	3639	3.42	24.91	8.20	6.86	1.20	2.30	26.00	77.50	1.0438	.3292	11.3043	Q
53.54	3124	3.13	21.28	6.00	5.68	1.00	1.94	22.00	77.50	1.0338	.2820	11.3402	R
54.33	3124	3.47	20.76	6.75	5.88	1.20	1.96	21.80	77.00	1.0501	.3251	11.1224	S
55.33	2990	3.03	18.68	5.70	4.70	.80	1.91	20.20	72.50	1.0814	.3051	10.5759	T
56.33	2731								74.25				U
57.33	2837	2.83	19.72	4.70	4.90	1.00	1.78	20.00	73.40	1.0142	.2383	11.2360	V
58.33	3119	2.74	20.71	5.70	5.49	.90	1.96	21.40	75.80	1.0333	.2752	10.9184	W
59.33	2847	2.74	20.71	5.80	4.90	.90	1.81	21.60	73.40	1.0430	.2801	11.9337	X
60.33	3173								73.40				Y
60.58	3484								78.00				Z
66.71	2205	3.61	11.42	7.20	4.70	1.20	1.45	15.40	62.00	1.3485	.6305	10.6207	a
67.33	2164	3.61	11.42	8.10	4.51	1.10	1.43	16.00	57.00	1.4011	.7093	11.1888	b
69.33	3243	2.98	21.80	7.20	5.98	1.30	1.96	23.40	67.00	1.0734	.3303	11.9388	c
70.33	3775	3.61	26.47	8.00	6.86	1.40	2.32	28.00	75.80	1.0578	.3022	12.0690	d
77.33	3892	3.71	26.47	7.90	6.86	1.20	2.27	27.40	72.50	1.0351	.2985	12.0705	e
78.33	3846	3.61	26.47	7.90	6.86	1.10	2.32	28.40	70.00	1.0729	.2985	12.2414	f

CENTRO DE INFORMACIÓN DE RECURSOS HÍDRICOS
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