ACTA GEOLOGICA HISPANICA, v. 28 (1993), nº 2-3, p. 15-25

High mountain basins in northern Chile: water balance problems in an arid volcanic area

POURRUT Pierre (1), COVARRUBIAS Alex (2)

(1) Institut Français de Recherche Scientifique pour le Développement en Coopération ORSTOM, Département de

(2) Universidad Católica del Norte UCN, Departamento de Ingeniería Civil Angamos 0610, BP 1280, Antofagasta, Chile.

ABSTRACT

In, the arid volcanic area of northern Chile, over 3,100 m, the overflow layer is very high and shows little variation in time. During dry years, it may exceed the precipitation layer and it seems independent from rainfalls. The natural overload is very scarce and the resources that actually are developed could be considerated as fossil groundwaters.

To explain these anomalous values of the water balance, the most likely hypotheses are three: 1 - missestimation of actual precipitations (infiltration of snow cover); 2 - existence of external contribution (drainage from the east below the volcanic range); 3 - discharge of powerful aquifers (1st, the climatic conditions in the Holocene have been much wetter than previously considered; 2nd, thick detritic formations are interstratificated in the volcanic complex).

1 - INTRODUCTION

Located be° 30' W long., on either side of the Tropic of Capricorn, the region of Antofagasta rises from the Pacific Ocean level up to more than 6000 m, elevation of the highest volcanoes of the Andes (Fig.1).

The region is characterized by its extreme aridity. Hydric resources are very limited but the mineral resources are abundant and they need important water volumes for present and future exploitation. The increase of hydric requirements for mining causes acutes conflicts with other consumption sectors and makes up a drawback for regional development.

2 - MAIN CHARACTERISTICS OF THE REGIONAL ENVIRONMENT

Rainfall and geology are the two main components of geographic environment that play an important role in the genesis of water resources.

2.1 - Pluviometric framework

The three main causes of the generalized regional aridity of northern Chile are: the almost permanent influence of the Southeastern Pacific Anticyclone, the proximity of the cold Humboldt Current and the presence of the Andean Range.

Along the coastline, highly influenced by the first two factors, the climate is stable. There are no large thermal variations, rainfall is almost totally lacking and water resources are particularly scarce.

To the east, the climate is controlled by the conditions proper to the Highlands, and particularly by the fact that the Range constitutes a barrier to Atlantic influences. Alternatively, the higher parts are influenced by Pacific air masses during austral winter and by continental air masses from December to March, period during which wet hot ascending air masses originated in the Paraguayian and Argentinian Chaco are pushed to the west. They produce rainfall and thunderburst, and peaks can be seen covered by the snowy layer characteristic of the bolivian or altiplanic winter. In relation to temperatures, high daily or seasonal thermal variations are detected.

Quantitative level: the available data records reflect the density of rainfall and climatological measurement stations. These are only a few, due to the great difficulties for access and because an extensive part of the territory is completely isolated during several months a year. The precipitation network, consequently gives an imperfect representation as compared with regional extension heterogeneity, on the one hand, and with respect to the desert conditions that are characterized by an extreme irregularity, on the other hand. It does not show the real number of rainfall events and does not allow a proper estimation of the space distribution of rain or of the water-equivalent of the snow precipitation in the highest areas. Anyway, it is still too early to define a synoptic pattern which can lead to forecast or which can even correlate some meteorological characteristics to snow or rainfall events, that are randomly occuring.

Rainfall data records are reliable only at a local scale and show that summer precipitation has a high interannual irregularity and make up about 90% of the pluviometric amount, meanwhile the other part of the year is normally dry.

2.2 - Geodynamical context

The subduction of the Nazca oceanic plate under the western edge of the continent, that is responsible for the seismic activity and active volcanism of the east zone, has also an influence at a structural level. Major parallel faults run approximately northeast-southwest and control a block-tectonic system which defines different morphostructural compartiments (Fig. 2). In relation to the sequence and constitution of the geological strata of the area, the traditional interpretation proposes that most outcropping rocks have a relatively recent igneous origin (plutons and volcanites). Also, in relation to detritic formations, the importance of which is relevant owing to their aquiferous potential, it can be quoted "...durante este período (Mioceno-Holoceno), imperó un clima hiper-árido, con escasa erosión, aunque se formaron extensas cubiertas aluviales y algunos depósitos lacustres y salinos, que constituyen las actuales planicies (pampas) y salares localizados en la Depresión Intermedia y Cuencas Intramontanas" (Boric et al., 1990)[1].

Quantitative level: the reliability of this thesis is questionable, but this may be because it does not provide the necessary details. This drawback is mainly due to the presence of a wide recent ignimbrite layer that covers numerous geological limits and tectonic accidents. It also reflects the fact that geological surveys were done almost exclusively from a mining viewpoint. It is interesting to note that in spite of the unavoidable erosion-sedimentation cycles resulting from the Andean orogenesis, such a pattern does not take into account the detrital deposits. It also implies that arid conditions have been permanent for about ten million years; thus, this interpretation excludes the hydric processes from the formation and deposition of thick layers of continental sediments existing in the intermediate region.

The whole study area corresponds to an extremely complex volcanic environment. The great number of episodes of magmatic-volcanic activity is shown through a sequence where volcanic lavas and tuffs, with diverse composition and large lateral heterogeneity, alternate. Besides, detrital formations resulting from altitudinal adjustments of the Andean uplift are interstratified and the whole sequence is often covered by recent stratovolcano cones and lavaflows.

3 - PRESENT RESEARCH PROGRAMME AND OBJECTIVES

Scientific cooperation between UCN and ORSTOM have as a purpose to remedy the water scarcity since 1991. One of the aims of the program is to understand the mechanisms that control the formation and circulation of surface flows and groundwaters.

In this perspective, the study proposes to quantify the value of the different components of the simplified water balance equation, built on the global model:
- 1 - INPUT, production function, or entrance to the hydrological system: This component corresponds essentially to the meteoric water; it is measured by series of observed rainfalls;

- 2 - TRANSFER, exchange function in the system: This component correspond to the physical/geological context; it deals with the separation of the runoff, the storage capability and the circulation velocity;

- 3 - OUTPUT, restitution function, or exit from the geographical framework: This component corresponds to the amount of water that is produced as a resultant of the previous functions. It is measured at the hydrometric stations located at the exit of the system.

Because of complexity of the geographical environment, and of the scarcity of available data, the study was primarily focused on:

- an inventary of the geological characteristics linked to water production;

- a wide sampling of meteoric waters, as well as superficial water and groundwater, for physico-chemical and isotopic analyses;

- the collection of basic field information and the establishment of a preliminary hydro-climatological network. The study areas included the endorheic watershed of Rio Zapaleri (in the altiplano, or puna), and the upper watershed of Rio Loa (the only exorheic river in the area);

- a critical analysis and processing of the existing data like the Rio Salado (an affluent of Rio Loa, Fig. 3) records. This watershed has been selected as one of the most representative basins in order to establish the first water balance available in this region. Analysis of these previous data (J. Köhnenkamp, [2]) showed several anomalies that we shall now examine.

4 - ANALYSIS OF THE RESULTS

4.1 - Preliminary results on a regional scale

Systematical geological reconnaissance led to re-examine some concepts. For instance, in the highest part of the watersheds, these studies led to identify some thick and wide continental units of post-Miocene age (Fm. El Loa conglomerates). Besides, detritic sediments and unconsolidated tuffs were found interstratified in some ignimbrite sequences (e.g. Toconce Fm.).

From the isotopic analyses, two types of results should be emphasized:

- snow profiles sampled in june 1993 indicate clearly that the water had a continental source;

- the almost total lack of 3H (confirmed by B. Messerli et al., 1993, [3]) in the water of the drainage net means that the water is older than 1945.

PRELIMINARY CONCLUSIONS: In first place, it can be inferred form the fact that some detritic formations results from strong hydric origin, that climatic conditions have been much wetter than previously considered. In this respect, the thick layers that show typical aquifer characteristics could be recharged at that time and constitute major reservoirs. As expressed by B. Messerli et al., 1993, [3]: "The early Holocene (11-7 kyr B.P.) experienced wetter conditions ... After about 3,000 B.P. conditions became drier; ...", one should forget the prevailing concepts about post-Miocene hyper-aridity.

On another hand, the results of the isotope analyses, which still need to be reconfirmed, point to the predominant role of the continental air masses. These results suggest that the rainfall mechanisms are rather complex. Finally, they indicate that overflow water in the drainage net is mainly of groundwater origin.

4.2 - Water balance in Salado River basin

Owing to its importance for water production (470 l/s for Antofagasta tap water plus 1,090 l/s to meet some of the requirements of Chuquicamata copper mine) the Salado River has been equiped with one of the oldest hydroclimatological observation networks of the region. This network gathered useful data even if some stations provided only episodical records.

This basin is located between 22° and 22°30' S lat., and 67° 45' W long. (Fig. 3), at elevations between + 2,530 and + 5,960 m and extends on 2,390 km .

The interesting area that controls the cordilleran system of water genesis in which are faced the major problems to equilibrate the terms of the hydric balance, is located over 3,100 m. This area, called upper basin involves the Sifon de Ayquina hydrometric station and measures 748 km .

Annual means of temperatures vary from 12° to 2°C according to the altitude (altitudinal gradient of 0.42°C/100m), with extreme values close to 30°C and lower than -15°C. The O°C isotherm, snow position index, is a function of the season of the year: it is fixed at 4,700 m (average temperatures) and 2,800 m (minimum temperatures) in July, while in January it rises up to 5,500 m and 4,200 m, respectively.

Although pluviometric data exist since 1968, a reliable statistical treatment can only be applied to series after 1974 (table 1). 90% rainfall is concentrated during the Bolivian winter, from December to March, while the austral winter does not show more than scarce and weak rainfall or snowfall that interrupt the intense dry period lasting the other part of the year. Daily rainfall rarely exceeds 40 mm, except for rainfalls observed in February 1977: 64 mm and 54 mm in Toconce; 47 mm and 50 mm in Linzor and 48.5 mm in Caspana. The rainy episode of the interval from February 13th to 26th, 1977, with exceptional pluviometric amounts: 239 in Toconce, 223 mm in Linzor and 160 mm in Caspana, are probably very scarce. The annual rainfall means, about 10 mm at the lowest point the basin (Loa River confluence), ranges from 50 mm up to almost 200 mm between the lower zone and the upper part of the upper basin.

Among the seven hydro-pluviometric existing stations, only three provide continuous information, being the upper basin control station, "Salado en sifón Ayquina", noticeable for the quality of the information. Its monthly and annual modules are shown in table 2. Floods are scarce, even none in some years, but peaks can reach great magnitudes, the highest being the one observed during the flood from February 16th to 25th, 1977: 288 m3/s, that is 367 l/s/km2. From 1975 to 1990, annual specific modules are fixed at about 2 l/s/km2, with monthly values between 25 l/s/km2 (February 1977) and 1.5 l/s/km2 (November 1979).

PRELIMINARY CONCLUSIONS: According to the methodology exposed in the chapter 3, table 3 presents the annual values of water input and output. In the upper basin, the 15-year-long observation series allows the following comments:

- the terms "deficit" and "overflow" have quite similar values during years with next-to-mean pluviometric frequency;- unless extremely abnormal events occur, such as those in 1976-77, the overflow layer shows little variation in time, with values of about 50 to 60 mm per year. In other words, it seems independent from rainfalls on the basin.

- during the dry years, the overflow layer is very high and may exceed the precipitation layer.

5 - PROBLEMATIC IDENTIFICATION AND INTERPRETATIVES HYPOTHESIS

The study of the results shows an imbalance between the input and the output of water to the hydrological system. According to the present knowledge, the whole physical-climatic characteristics cannot explain the strongly anomalous value of the overflow layers.

Besides the mentioned desequilibrium, it is observed that groundwater of remote origin is playing a predominant role in the flows of the drainage net. It would show that, nowadays, the natural overload is very scarce, almost nil and could also reflect a very long transit underground.

In some way, the runoff watched in the rivers and the resources that actually are developed could be considered as fossil waters.

The anomalous values and the difficulties for equilibrating the terms of the equation from water balance can have its origin in a missestimation of a true value of its components or in the unknown intervening processes. Between the various posible hypotheses, the most likely are the following:

- Hypothesis 1: Missestimation of actual rainfalls: Due to the absence of registering devices in the higher points, pluviometry is probably underestimated. Moreover, we cannot evaluate the contribution of solid precipitation and the snow cover, the infiltration of which could notably increase the value of the entry variable.

- Hypothesis 2: Existence of external contribution: The drainage net, constituted by the intense regional fault and the block-tectonic system, could drive waters from outside the studied area. Maybe from bolivian altiplano (although there is no evidence). It cannot be forgotten that H. Cusicanqui et al. (1975) and W. F. Giggenbach (1978), [4], proved that thermal waters of El Tatio geothermic field are derivated from precipitations fallen in the oriental sector, the same that, on its migration through west and passing below the volcanic chain, acquire their chemical composition and temperature. A contribution of youthful volcanic waters is also possible, though probably limitated.

- Hypothesis 3: Discharge of powerful aquifers: Between the formations of the volcanic complexes would be interstratificated powerful aquifer layers with very important reservoirs. Due to the acumulation of waters until higher altitudes, the ground waters would be found with hydraulic charge and would discharge to the drainage net a flow that may be limitated, but continous and independent from precipitations. This hypothesis, in association with hypothesis number 1, is most likely but needs imperative conditions. Some of them have been already partially investigated in the view of the present studies: need of palaeoclimatological conditions different from actual aridity and the existence of enough reservoir-rock volume.

In any case, these hypotheses are meant to be a referential baseline to define the topics, methodologies, techniques and instrumentation that should be set to contribute with the necessary elements to understand the mechanisms that rule the constitution and circulation of waters in the system.

6 - RESEARCH TO COME: METHODS AND TECHNIQUES

The future studies are based on the mentioned hypotheses. They refer to three different aspects and time scales of fluctuation of the water cycle in reponse to climatic changes:

- interannual: evolution of the snow cover at high altitudes;
- centennal: evolution of surface and groundwaters in systems of internal drainage;
- last 20,000 years: palaeohydrological and palaeoclimatological fluctuatios of groundwater and surface water systems.

6.1 - Evolution of the snow cover

PROBLEMS: It is here considered that snow is the main source of precipitation. The snow cover can undergo several processes of evolution: evaporation in the solid form, melting (evaporation in the liquid form, surface run-off and infiltration) and transformation into ice. The characterization and separation of these different processes will involve:

- an evaluation of the annual average of accumulation in relation with the origin of the atmospheric vapor and with the condensation processes;
- an attempt to correlate the identified processes of evolution to large scale meteorological and climatic parameter.

METHODS and TECHNIQUES: The studies will encompass the following techniques:

- satellite imagery to define the origin of the atmospheric condensing vapor;
- snowgauging for determination of the water equivalent, by using gamma-neutrons gauging;
- estimation of sublimation by measurement of the content in salt of meteoric origin (Cl-, Br-) and of the snow, with automatic sampler (ORSTOM technology);
- evaluation of the ablation out of the melting zone by rainfall and flow gauging; the data collection system will use autonomous and transmitting recorders:
* electronic and computer device for measurement of level and temperature water SPI III, connected to the CHLOE-D limnimetric recorder (ELSYDE/ORSTOM)
* self power recording and transmitting rainfall data system LOGGER 91 (ELSYDE)
* field data transmission to satellite with capability of telemetring: ARGOS system with SRDA direct readout station
- extrapolation of the process of ablation/accumulation at the local scale to the general scale by satellite imagery NOAA, SPOT, ERS1 (radar wavelength) and GOES;
- comparaison of the water balance obtained with the ice balance, through ORSTOM studies on glaciers in Perou and Equator;
- global comparaison with net radiation balance at the stations.

EXPECTED RESULTS: The studies would provide:

- estimates of the amount of snow and fraction of it which is available for the renewal of water resources;
- in Perou and Equator, evaluation of the relative importance of precipitation and temperature seasonal increase or decrease, to account for the general retreat of glaciers.

The simultaneous comparaison with satellite data will allow to generalize the mechanisms at the scale of a large part of Andean range. The corresponding time scale is of some years, in the case of snow, and of some decades, in the case of ice.

6.2 - Evolution of surface flows and groundwaters in systems of internal drainage

PROBLEMS: Water derived from snow melting can infiltrate or flow at the surface. A good knowledge of of the relations between these two parameters will constrain any plans of management of water resources because of the sensitivity of the water cycle to short term climatic fluctuation. Of special relevance with that respect are:

- the very high evaporation rates, with increase in salinity in zones of poor drainage;
- the large variations in permeability of the rocks which model the aquifer system;
- the contribution of perivolcanics emanations which can add various amounts of indesirable chemical components (As, Hg, B) in groundwaters.

This part of the study will investigate:

- the infiltration rate from snowmelt;
- the origin and age of waters in the surface flows and in the aquifers;
- the mechanisms of salinization by evaporation and by dissolution of soluble salts.

METHODS: Emphasis will be put on:

- soils profiles in the zones of snow melting to investigate the infiltration rate by tensiometry and neutron gauge measurements;
- measurements of stable isotopes (2H and 18O) and tritium concentrations of pore waters form the same soil profiles to determinate the fluctuation of the recharge rates;
- flow measurements in some selected sections of rios Zapaleri and upper Loa;
- chemical, stable isotope and radiocarbon (14C and 13C) measurements in surface waters to estimate the conditions of drainage in permanent rivers (selected sections of rio Loa);
- chemical and isotope studies, including volatile components, of El Tatio geothermal field.

EXPECTED RESULTS: This part of the studies will provide informations on hydrological variations at the scale of some decades to some centuries, and will allow to discuss the related influence of recent climatic changes and hydrological events.

6.3 - Palaeohydrological and palaeoclimatological fluctuations

PROBLEMS: This part of the studies aims to a synthesis of all the previous researches for a better understanding of environmental and climatic changes in the arid and semi-arid zones of the Andes.

Due to the relatively recent uplift of the Andean Mountain Range and to the low precipitation over the reliefs, most of the basins are of internal drainage. This implies that the terminal lakes of the surface network are preserving the record of environmental conditions during sedimentation. Most of these basins are presently evolving as saline depressions (salares) but during humid periods or when exceptional precipitation events occurred, groundwater drainage was reactivated and fresh or brackish lakes could develop. This part of the studies aims to identify theses fluctuations at various times scales and to relate them to natural and man-induced changes in hydrological and environmental conditions.

A clear separation between summer and winter precipitation and snow fall events is required for a proper palaeohydrological interpretation. Furthermore, it would be interesting to try to correlate the patterns of recent precipitation and atmospheric circulations to the El Niño events.

BASIN SELECTION AND TECHNIQUES: For its climatic, hydrological, geological and geomorphological conditions, the closed depression of the salar of Atacama has been selected. Detailed studies of high lake levels will be combined with piston coring up to 40 m of bottom soft sediments. The following techniques will be used:
- dating: 14C and 230Th/234U;
- geochemical studies: major and trace elements (Sr/Ca and Mg/Ca), stables isotopes;
- sedimentology/mineralogy/density;
- bioindicators (pollens, diatoms, ostracods, etc.);
- further analytical studies depending on field work conditions.

EXPECTED RESULTS: Assuming a reasonable sedimentation rate of 1 to 2 mm.a-1, a time period up to 20 ka could be explored. This range covers the Last Glacial Maximum, the deglaciation period and the climatic oscillations of the Holocene.

The first purpose is to compare the fluctuations recorded in sediments with those obtained in other sites of the region and with the general scheme of climatic evolution recorded from other parts of the world. At the global scale, the studies will contribute to the debate on the coupling, or decoupling, of Northern and Southern Hemisphere in their responses to orbital or non-orbital forcing during the Post Glacial period and the Holocene. At the regional scale, the studies are expected to contribute to a better definition of the occurrence of major El Niño events.

NOTE: All the studies will provide related contribution to several international Global Change Programmes (IGBP, PAGES, PEP, Palaeomonsoon, etc.). Under UCN and ORSTOM coordination, will participate various research institutes as Laboratoire d'Hydrologie et Géochimie Isotopique, Université de Orsay-Paris XI, Laboratoire de Glaciologie et Géophysique de l'Environnement, Université de Grenoble, France, Dipartimento di Scienze della Terra, Universita di Torino, Italy, Department of Physical Geography, University of

Berne, Swiss, Institut of Geographie, University of Erlangen-Nürnberg, Germany, Niedersächsischer Landsamt für Budenforschung 14C Laboratory Hannover, Germany, and Escuela de Ingeniería Civil de Madrid, España. The extended program will be presented for external financiation to CEE-DG12-"Environment" and ECOS of France.

REFERENCES:

[1] BORIC Ricardo, DIAZ Felipe, MAKSAEV Victor - Geología y yacimientos metalíferos de la Región de Antofagasta, SERNAGEOMIN CHILE, Boletin Nº 40, 1990.

[2] KÖHNENKAMP Guillermo Javier - Balance y caracterización de los recursos de agua superficiales de la cuenca del río Salado, memoria de título de ingeniero civil, convenio UCN-ORSTOM, Antofagasta, 1993.

[3] MESSERLI Bruno, GROSJEAN Martin, BONANI Georges et al. - Climate change and natural resource dynamics of the Atacama Altiplano during the last 18,000 years: a preliminar synthesis, in Mountain Research and Development, Vol. 13, Nº 2, 1993, pp 117-127.

[4] GIGGENBACH Werner - The isotopic composition of waters from El Tatio geothermal field, Northern Chile, Geochimica et Cosmochimica Acta, Vol. 42, 1978, pp 979-988.

Table 1. Annual Rainfall of Rio Salado Basin (mm)(*)

STATION	74-75	75-76	76-77	77-78	78-79	79-80	80-81	81-82	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90	PROM
CHIU-CHIU	6.9	10.0	3.5	1.1	9.5	0.0	1.5	1.0	9.5	14.0	2.5	12.0	24.0	2.0	3.0	0.0	6.3
AYQUINA	91.2	44.0	104.3	18.5	23.0	17.6	28.0	7.0	18.5	86.5	27.2	65.5	90.5	9.5	43.0	6.5	42.6
TURI	106.3	50.0	132.9	25.0	28.1	17.9	30.0	8.6	16.3	96.5	48.8	76.0	86.0	10.0	68.0	8.0	50.5
CUPO	183.0	90.1	159.4	18.6	47.0	3.2	33.6	5.6	17.2	201.4	112.0	79.8	100.7	27.5	77.0	7.5	72.7
CASPANA	168.0	113.7	180.5	38.5	46.5	12.0	74.5	11.1	34.1	178.0	47.8	79.1	125.0	15.5	95.0	24.0	77.7
SALADO EMB.	157.8	85.5	175.0	23.0	19.5	14.0	67.0	13.0	22.0	177.3	68.4	107.4	110.9	22.3	102.3	27.2	74.5
TOCONCE	278.3	125.0	264.0	25.0	44.7	24.1	68.6	22.0	36.4	245.6	137.5	118.3	164.0	40.5	123.3	42.7	110.0
EL TATIO	382.2	274.7	312.1	89.1	144.9	54.6	127.2	51.7	124.0	367.9	234.7	155.8	338.1	72.7	134.7	63.6	183.0
LINZOR	411.5	298.4	345.0	82.5	114.2	84.5	182.0	53.0	123.9	353.0	233.2	145.0	279.1	72.6	169.3	31.0	186.1
CONCHI EMB.	44.7	8.8	35.0	15.5	34.0	8.0	16.0	4.0	21.5	42.5	17.5	19.0	39.1	3.5	10.5	1.5	20.1
O. DE S.PEDRO	163.9	175.7	117.6	37.7	66.7	94.5	65.0	33.3	59.0	120.0	148.0	82.7	104.3	21.7	48.5	34.5	85.8
RIO GRANDE	222.5	133.0	168.0	35.9	68.2	30.1	114.9	9.1	59.3	234.5	95.5	104.3	159.9	9.0	89.6	25.5	97.5
AVERAGE	200.1	121.9	185.9	36.0	55.3	24.8	67.7	18.1	44.4	194.0	100.4	92.0	147.1	29.3	88.8	22.2	89.2
U. BAS. AVER.	316.0	214.9	276.8	63.8	94.1	48.2	119.7	37.4	87.3	294.1	172.5	129.3	239.3	53.4	131.6	40.5	144.9

(*) Hydrological year starts on November 1st.

Table 2. Average Flows in "Rio Salado - Sifón Ayquina" (m /s)

YEAR							MONTH						MEAN
	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	YEAR
75-76	-	-	2.730	1.613	1.476	1.266	1.276	1.433	1.435	1.411	1.428	1.326	1.539
76-77	1.333	1.310	1.481	19.660	2.080	1.555	1.461	1.476	1.409	1.365	1.338	1.274	2.979
77-78	1.263	1.264	1.365	1.395	1.407	1.407	1.416	1.460	1.460	1.471	1.338	1.340	1.382
78-79	1.268	1.328	1.545	1.245	1.277	1.218	1.254	1.268	1.253	1.259	1.226	1.208	1.279
79-80	1.195	1.229	1.238	1.274	1.488	1.409	1.403	1.444	1.480	1.430	1.510	1.425	1.377
80-81	1.406	1.400	1.467	2.037	1.476	1.469	1.442	1.426	1.436	1.479	1.471	1.358	1.489
81-82	1.316	1.307	1.358	1.403	1.413	1.358	1.337	1.312	1.298	1.332	1.392	1.335	1.347
82-83	1.307	1.372	1.401	1.397	1.429	1.307	1.393	1.381	1.378	1.354	1.490	1.314	1.377
83-84	1.266	1.273	2.880	1.827	1.453	1.338	1.368	1.413	1.440	1.417	1.396	1.351	1.535
84-85	1.327	1.302	1.379	1.911	2.440	1.361	1.349	1.390	1.392	1.335	1.350	1.344	1.490
85-86	1.326	1.339	1.537	1.663	1.351	1.348	1.342	1.337	1.331	1.398	1.326	1.316	1.385
86-87	1.346	1.458	2.448	1.503	1.759	1.325	1.344	1.323	1.303	1.341	1.280	1.280	1.476
87-88	1.253	1.276	1.378	1.389	1.459	1.335	1.351	1.321	1.289	1.291	1.269	1.250	1.323
88-89	1.272	1.294	1.360	2.490	1.425	1.368	1.417	1.411	1.365	1.349	1.371	1.338	1.455
89-90	1.302	1.305	1.347	1.369	1.330	1.305	1.332	1.341	1.341	1.305	1.297	1.254	1.319
AVERAG	1.299	1.318	1.661	2.812	1.552	1.358	1.366	1.382	1.374	1.369	1.365	1.314	1.517

Table 3. Preliminar Hydric Balance of Rio Salado Basin

PERIOD HYDR. YEAR	BASIN	PRECIPIT. mm	RUNOF mm	DEFICIT mm	COEF. OF RUNOFF (%)
75-90	UPPER	134	70	64	52,2
	TOTAL	82	23	59	28,0
75-76	UPPER	215	62	153	28,8
	TOTAL	122	23	99	18,9
76-77	UPPER	277	120	157	43,3
	TOTAL	186	43	143	23,1
77-78	UPPER	64	56	8	87,5
	TOTAL	36	21	15	58,3
78-79	UPPER	94	51	43	54,3
	TOTAL	55	20	35	36,4
79-80	UPPER	48	55	-7	114,6
	TOTAL	25	21	4	84,0
80-81	UPPER	120	60	60	50,0
	TOTAL	68	23	45	33,8
81-82	UPPER	37	54	-17	145,9
	TOTAL	18	21	-3	116,7
82-83	UPPER	87	55	32	63,2
	TOTAL	44	21	23	47,7
83-84	UPPER	294	62	232	21,1
	TOTAL	194	23	171	11,9
84-85	UPPER	172	60	112	34,9
	TOTAL	100	23	77	23,0
85-86	UPPER	129	55	74	42,6
	TOTAL	92	21	71	22,8
86-87	UPPER	239	58	181	24,3
	TOTAL	147	22	125	15,0
87-88	UPPER	53	53	0	100,0
	TOTAL	29	20	9	69,0
88-89	UPPER	132	59	73	44,7
	TOTAL	89	22	67	24,7
89-90	UPPER	41	54	-13	131,7
	TOTAL	22	21	1	195,5

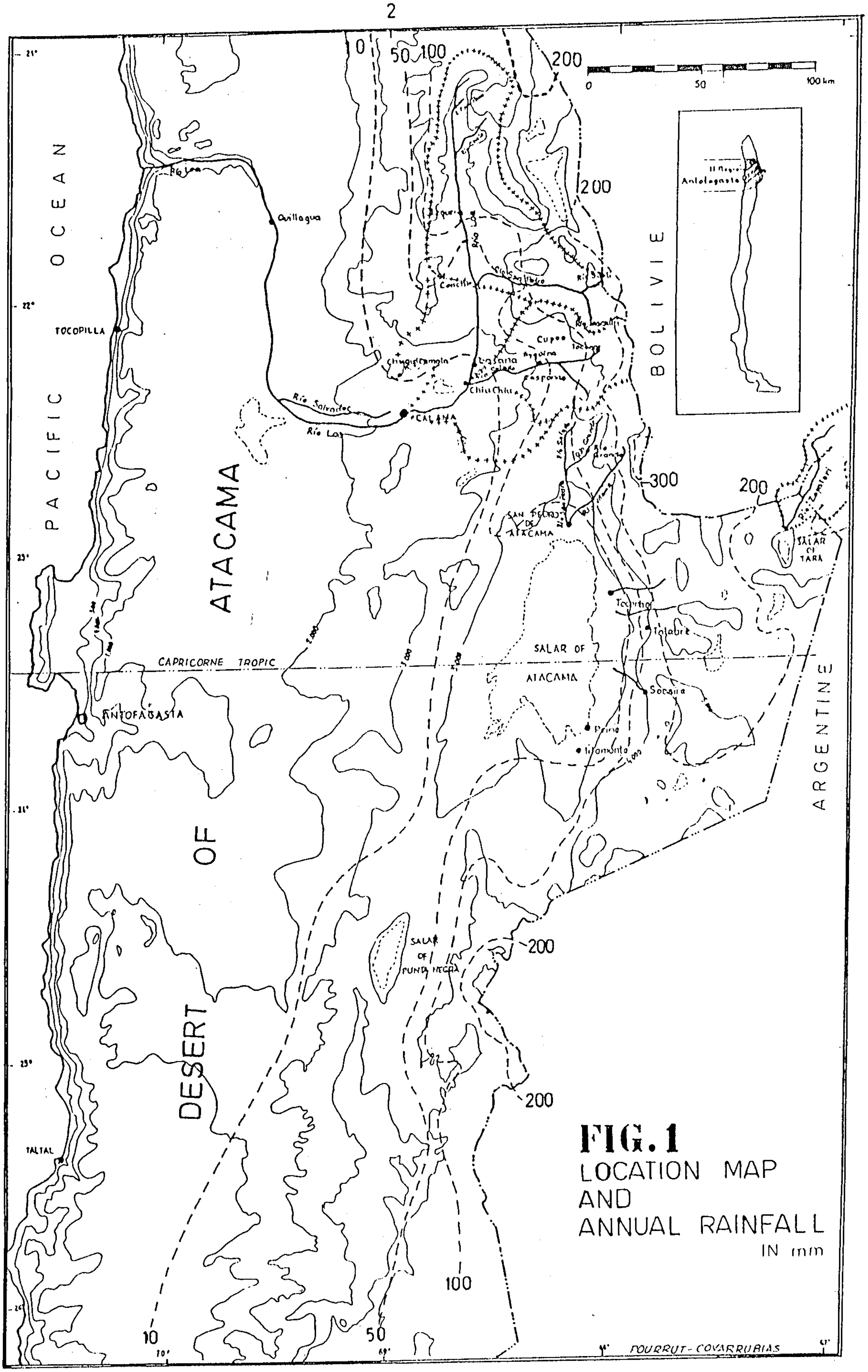

FIG. 1
LOCATION MAP
AND
ANNUAL RAINFALL
IN mm

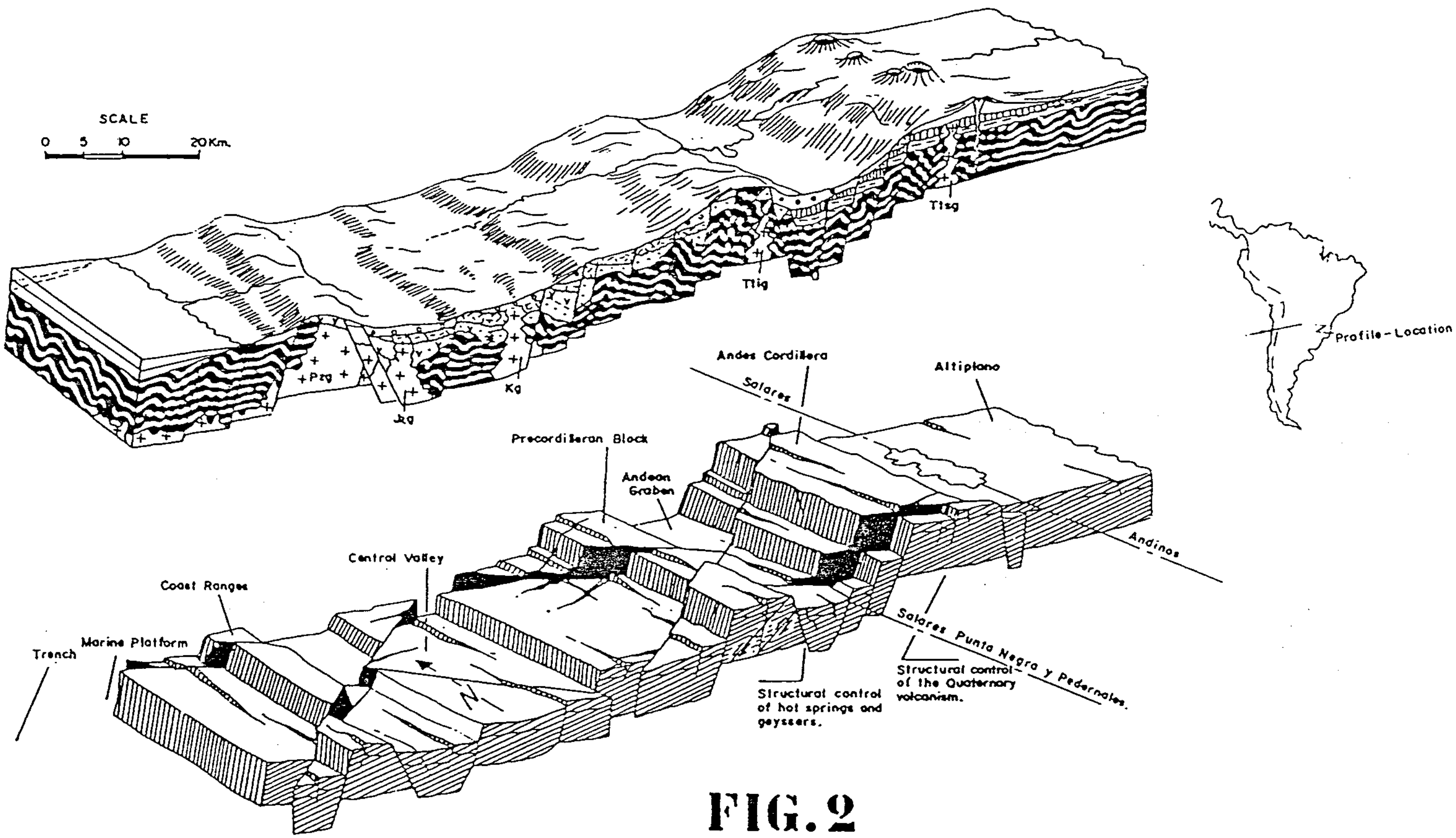

FIG. 2

GEOTECTONICAL DIAGRAM

SOURCE: FRUTOS, J., 1975
Annualres Soc. Géol de Belgique

POURRUT-COVARRUBIAS

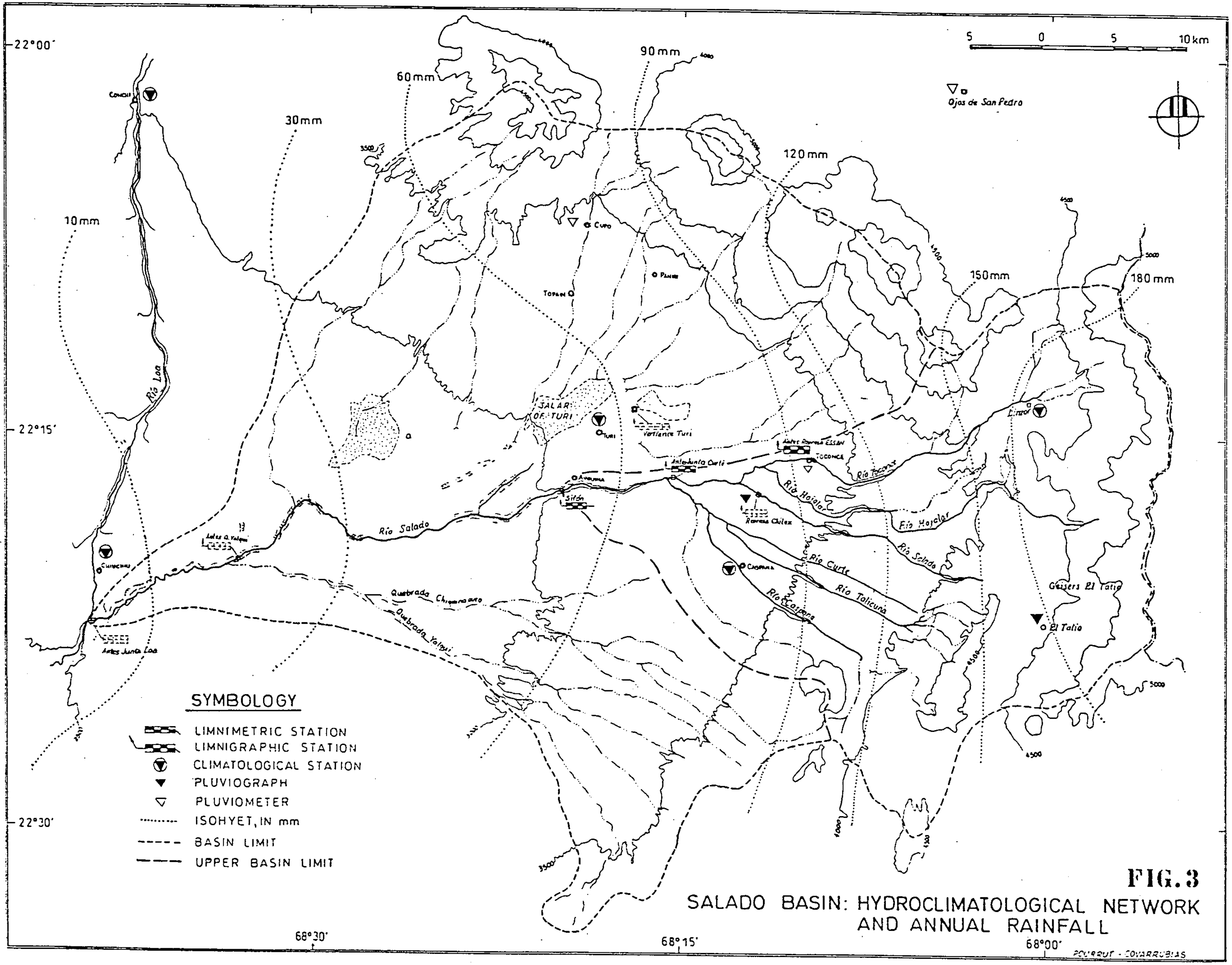

FIG. 3

SALADO BASIN: HYDROCLIMATOLOGICAL NETWORK AND ANNUAL RAINFALL