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HYDROGEOLOGICAL INVESTIGATIONS IN THE PAMPA OF ARGENTINA

Dr. Dieter BANNERT

Bundesanstalt für Bodenforschung
(Federal Geological Survey)

3 Hannover 23
Stilleweg 2, Postfach 23 01 53
Fed. Rep. of Germany

November 1974

Type III Report

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14. Supplementary Notes

Co-Investigators:

Dr. H. Bender, Federal Geological Survey

Dr. W. Kruck, Federal Geological Survey

Lic. J.J. Lago, Section of the Subsecretary of Water Resources of the Argentine Republic

The coordinator in Argentina was Lic. Carlos Schroeder, Section of the Subsecretary of Water Resources of the Argentine Republic

The analysis was mainly carried out by Dr. W. Kruck. Parts of the results have been presented at the following meetings:

3rd ERTS-1 Symposium, Washington, Dec. 1973

Commitee on Space Research (COSPAR), Sao Paulo, June 1974.

15. Abstract

The correlation between thematic maps of the German Hydrogeological Mission and ERTS imagery of the Pampa plain made it possible to improve the accuracy of ground water quality maps.

Use of ERTS imagery in future expansion of hydrogeological investigation into neighbouring areas will result in considerable reduction of field costs.

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1. PREFACE:

The multispectral investigation of ERTS-1 imagery has added detailed knowledge to the results of ground water investigations achieved by conventional ground survey in the Argentine Pampa. A number of natural features and units of the earth's surface have been identified and delineated on the imagery. These features are closely related to conditions in the near surface ground water bodies. It can be demonstrated:

- that the outlining of different ground water areas, e.g.: differences in depth to ground water and salinity can be effected more precisely by combining ground survey with the use of ERTS-1 imagery.
- that the different ground water areas can probably be detected and outlined on ERTS imagery at any time during the year.
- that it is possible to produce maps showing depth to ground water in areas with similar geological and hydrogeological conditions.

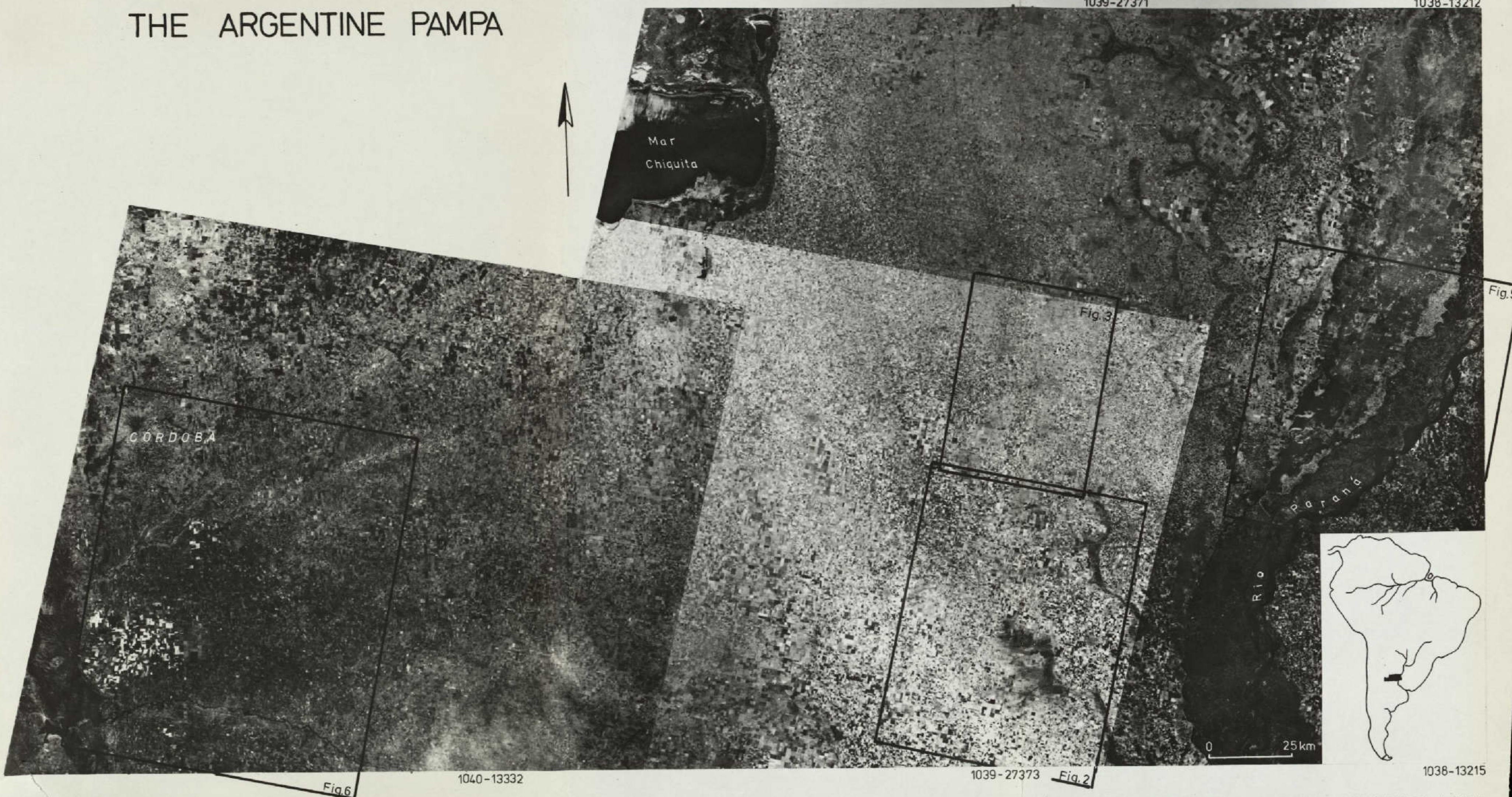
It can be assumed that the rest of the Pampa can now be surveyed with a 75 % reduction of ground survey observation points.

2. INTRODUCTION

Increasing demand for potable ground water in addition to stock watering led to a large scale hydrogeological investigation of about 50.000 sqkms of the Argentine Pampa. The area is situated between the Sierra de Córdoba in the West and the Rio Paraná in the East.(fig. 1 and fig. 7).

A team of hydrogeologists and technicians from the Federal Geological Survey of Germany, known as the Deutsche Hydrogeologische Mission (DHGM), under a Technical Aid Program, conducted hydrogeological investigations in cooperation with Argentinian Organizations (Subsecretaría de Recursos Hídricos) during the years 1969 - 1973.

THE ARGENTINE PAMPA



ERTS-1 MOSAIC OF THE PROJECT AREA
KEY TO PHOTO ILLUSTRATIONS

Fig. 1

Their main task was to establish a ground water survey to monitor run-off, infiltration and exploitation of ground water. In addition to outline potential ground water reserves for future use. The area of investigation lies roughly between $30^{o}40'$ to 32^{o}S and 60^{o} to $64^{o}30'$W (fig. 1 and fig. 7).

To complement the ground survey ERTS-A seemed to meet 2 important requirements:

- As a method to gain a synoptic overlook from the project area as rapidly as possible.
- The possibility to extract ground water related features from the imagery.

When setting up the ERTS-A proposal entitled: "Hydrogeological Investigation in the Pampa of Argentina" it was assumed that the vegetation should show differences due to the different depth to ground water and different ground water salinity. As an example the evaluation of Apollo 9 SO 65 experiment photographs from the Mississippi Valley (AS 9 - 26A - 3741 A through D) led to the assumption that multispectral investigation of the vegetational pattern in a comparable region could be successful in identifying areas of different ground water conditions. Also it seemed to be desirable to have repetitive coverage over the test site to monitor the vegetation growth during an annual cycle to delineate stressed vegetation against nutriated vegetation. As the following investigation demonstrates a onetime coverage furnished adequate results.

Over the whole area about 7500 dug wells and bore holes have been observed and measured. With the assistance of topographic maps ground water level maps were compiled, showing the depth to ground water. Electrical conductance readings and chemical analysis led to the delineation of areas with fresh and saline ground water. However the accuracy of isolines (e.G.: Depth to ground water, salinity of ground water) is determined by the distances of observation points.

Since 1973 it has been possible to complement the ground survey by evaluation of ERTS-1 imagery.

ERTS-1 proposal SR 330 has been submitted to obtain data which have to meet the following constraints:

- cloudfree overpasses,
- full coverage of the test site during one cycle,
- repetitive coverage during different periods of the year,
- rapid acces to the data.

ERTS-1 imaged the test site in three passes on the following days:

30.8.1972	Eastern sector
31.8.1972	Central sector
1.9.1972	Western sector

The data have been shipped to the P.I. in December 1973.

3. DATA HANDLING AND ANALYSIS

ERTS-1 imagery was available in paper print form and also as positive transparencies. The 9" X 9" positives were converted to negatives from which 18" X 18" positive paper prints, with a scale of 1 : 500 000, were produced. These enlargements provided the basic data for the investigation. Overlays of the results were then converted to maps. The comparison of these "space" data maps with the hydrogeological maps derived from conventional observations showed that significant improvements could be achieved. Classification of the units outlined on the images could be done confidently as they were supported by knowledge obtained from the results of the previous field work.

The quality of the imagery is excellent. From the coverage period 30.8.1972 - 1.9.1972 the whole test site except the extreme NW is available. Additional coverage of parts of the site were acquired on 1.3.1973, 19.3.1973 and 26.3.1973. The investigations were carried out with the 30.8. - 1.9.1972 data. Additional control was established by cross checking the repetitive coverage.

Due to the delay during data processing and shipment and the termination of the hydrogeological team field survey, a direct feed back of the results into the field teams could not be established.

4. HYDROGEOLOGICAL CONDITIONS OF THE PAMPA AND THEIR CHARACTERISTICS ON ERTS-1 IMAGES

4.1 Areas with varying ground water salinity

The water level of an upper ground water body is situated within quaternary loess sediments between 0 and 25 m below the surface. The ground survey revealed a relationship between morphology, depth to ground water and salinity of ground water. This relationship is reflected by a number of features and units at the earth's surface, and can therefore be observed on ERTS-1 imagery.

Regions with different grey tones on the imagery represent different types and density of vegetation. This is closely related to the depth to ground water. Generally, ground water mineralisation and the salt content in the soil, increases due to the influence of evapotransporation with decreasing depth to ground water. High ground water salinity and soil salinity lead to unfavourable growth conditions for plants with high chlorophyll content. These regions appear dark in channel 7 and light in channel 5 (fig. 2).

The best growth conditions prevail in regions where the ground water level is situated below the area of influence of evapotranspiration (about 10 m or deeper). They appear predominantly light in channel 7 and dark in channel 5 indicating a dense coverage of vegetation with a high chlorophyll content.

The identification of different units was carried out using channel 5 images which provided the best contrast for this type of interpretation (fig. 2).

4a

1039-27373-5

Areas of differing ground water salinity 75 km SW of Santa Fé

UI – UIV show different salinity of ground water

b = Bajos

0 25 km

Fig.: 2

Unit I (UI)

Image indication: Very dark areas caused by high soil moisture, sparsely cultivated; e.g..: Borders of the Rio Paraná affluents and lowlands in the North of lagoon Mar Chiquita. (See also: Terraces of the Rio Paraná, LT and UT, in Fig. 5.)

Vegetation: Shrub and salt-bush.

Hydrogeological conditions: Depth to ground water less than 0,5 m; high ground water salinity.

Unit II (UII)

Image indication: Light areas with indistinct field pattern, e.g.: Surroundings of Rio Paraná affluents.

Vegetation: Shrub, salt-bush and sparse natural pasture.

Hydrogeological conditions: Depth to ground water up to about 5 m; high ground water salinity.

Unit III (UIII)

Image indication: Light areas with distinct field pattern.

Vegetation: Pasture and agriculture.

Hydrogeological conditions: Depth to ground water up to about 10 m, medium salinity of ground water.

Unit IV (UIV)

Image Indication: Dark areas with distinct field pattern.

Vegetation: Pasture and agriculture.

Hydrogeological
conditions: Depth to ground water more than 10 m. Medium to low salinity of ground water.

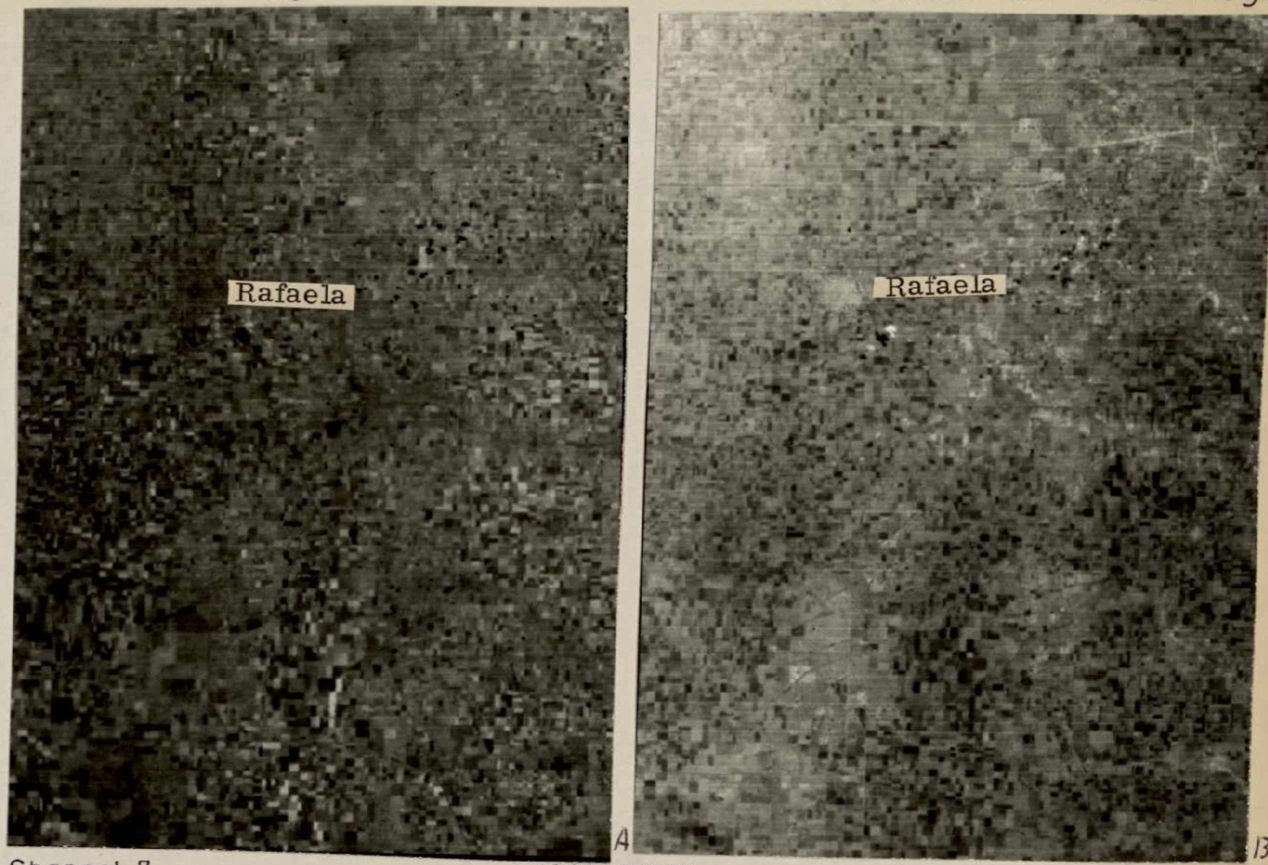
Because of similar phenology, irrigated farmland (fig. 6, unit A_i) cannot be distinguished from non irrigated farmland of UIV (fig. 2).
In fig. 3 A and B the Rafaela region is shown on channel 7 and channel 5 to demonstrate the better interpretability of channel 5 due to the wider range of contrast. Covering the same area are two maps of depth to ground water as shown in fig. 3 C and D. The isolines of fig. 3 C were constructed exclusively from a computer printout of depth to ground water of all observation points. In fig. 3 D an interpretation of channel 5 was combined with fig. 3 B. The inaccuracy of the isolines resulting from the distances between the observation points (1 km and more) in fig. 3 C could be compensated by the use of ERTS-1 imagery.

4.2 "Bajos"

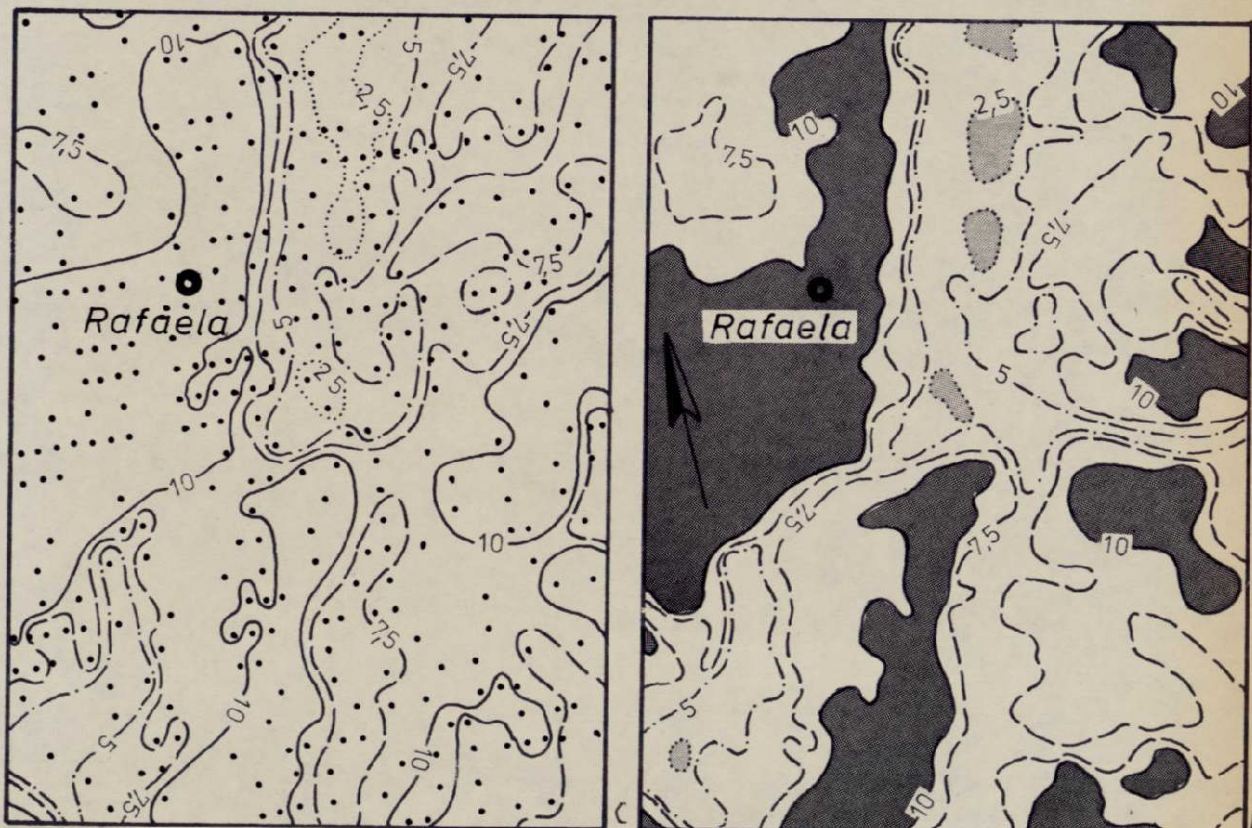
The most important resources of fresh ground water in the Central Pampa are situated below "Bajos".
"Bajo" is an Argentinian term to describe elongated flat depressions with little or no surface drainage. In space imagery they appear as sharply defined strips (b in fig. 2). They run more or less straight in an ENE-WSW direction, are between 100 and 200 m wide and are spaced at relatively even distances of approximately 2 km apart.

The consistent pattern of the Bajos throughout the Pampa region suggests a tectonic origin, probably due to fractures in the deeper crystalline bedrock.

Isolines of depth to ground water after field measurements and ERTS imagery



Channel 7 1039–27373 Channel 5



Isolines by computer print after field measurements

Isolines reconstructed from computer print in conjunction with ERTS image channel 5

Observation points

Isolines of depth to ground water in meters

Depth to ground water more than 10 m

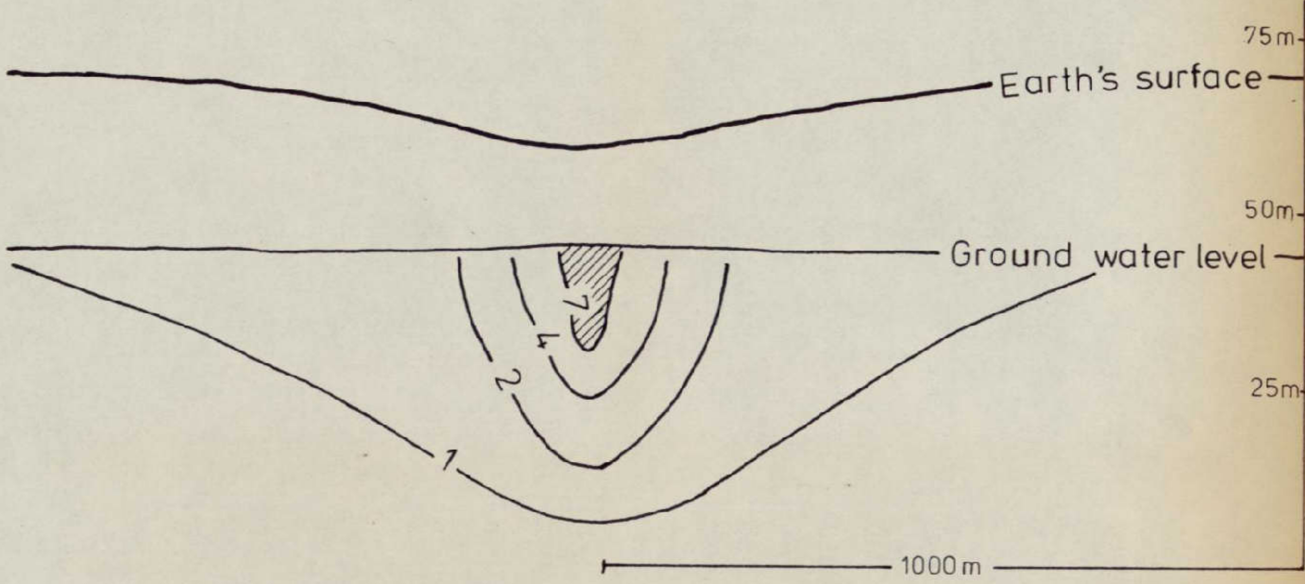
Depth to ground water less than 2,5 m

0 25 km

6 a

Fig. 3

Simplified cross section of a "Bajo"
(with the aid of geo-electrical profiles)



-4- Isolines of apparent resistivity (Ohm · m)

Fresh ground water (7 Ohm · m)

7 Ohm · m	~ 1	g / l	salt content
4 "	~ 1,8	"	"
2 "	~ 3,5	"	"
1 "	~ 7	"	"

after report DHGM Argentina 1973

Fig. 4

After heavy rainfall water collects in the Bajos where more water infiltrates than in the surrounding area. As a result, under the Bajo, fresh water lenses are formed in the saline ground water body, thereby offering water supply possibilities for rural needs (fig. 4).

Geophysical research and pumping tests revealed that for the calculation of fresh water (salt content lower than 1 g/l) a medium thickness of 20 m can be interpolated. The volume of the fresh water impregnated sediment therefore can be calculated from space imagery by using the formula:

$$V = W \times L \times T$$

V = Volume of the fresh water saturated sediment

W = Width of the Bajo

L = Length of the Bajo

T = Known medium thickness of the fresh water filled sediment

About 10 % of the Volume is assumed to be the total quantity of extractable fresh ground water.

4.3 Sand dunes on the terraces of the Rio Paraná

On the Eastern edge of the mainly dark colored upper terrace of the Rio Paraná is situated a sand dune field that appears as a white stripe in the imagery (fig. 5).

The depth to ground water in the terrace bed extends to about 1 m, in the sand dunes up to 5 m. The salt content of the ground water differs considerably. In the sand dunes, ground water with a salt content of about 0.3 g/l was found, whereas in the remaining terrace area the salt content exceeds in some cases 6 g/l.

The relationship between depth to ground water and ground water salinity is also most evident in this area, but the lower range of the capillary fringe in the sandy sediments permits the existence of fresh ground water at more shallow depths.

5. HYDROLOGY

From a hydrological point of view the area can be subdivided into three parts which are clearly visible on ERTS-1 imagery.

5.1 The river system of the Rio Paraná and its affluents

The East of the imaged area is dominated by the Rio Paraná and its terraces. The upper and lower terrace can be distinctly delineated (fig. 5, UT and LT). The lower terrace appears darker than the upper terrace due to a more intense soil moisture. The terraces are partly covered by open waters and meandering streams. Dark grey patches on the image stretching from North to South, to the West of the upper terrace, could be identified as swamp (S in fig. 5). Probably they represent the location of another older terrace.

5.2 The Central Pampa

The Central Pampa is almost completely flat. The imagery reveals that this part of the Pampa has no surface run-off, because no drainage pattern can be observed.

5.3 The Western Pampa

The Western part of the investigated area is intersected by three rivers, the Rio Primero, Rio Segundo and Rio Tercero flowing down from the Sierra de Córdoba.

At the moment of imaging both the Rio Primero and the Rio Segundo contained water but only in their upper courses. On the other hand the Rio Tercero contained water throughout its length as shown in the imaged scene of fig. 6. In channel 7 the water filled sections appear dark grey whereas the dry lower courses appear light grey (fig. 6). The sides of the rivers show dry beds of ancient rivers appearing as light grey stripes.

Rio Paraná, NE of Santa Fé

LT Lower Terrace

UT Upper Terrace

D Dunes (Upper Terrace)

S Swamp

P Pampa Plain

L Lagoon

0 25 km

Fig.: 5

ERTS-1 1038-13212-7

8a

Region SE of Cordoba ERTS-1, 1040-13 332-5

Old River Beds

A Region without drainage pattern

A_i Irrigated part of region A

0 25 km

Fig.: 6

8 B

6. PHOTOLINEATIONS (TECTONICAL PATTERN)

Apart from the "Bajos", for which a reasonable tectonic origin has been put forward, other long photolineations also possibly of tectonic origin could be observed on ERTS-1 imagery (fig. 7). Their relationship to hydrogeology has not yet been examined. Possibly they allow interaction between different overlying aquifers. However a more detailed ground water observation and hydrochemical survey, of numerous perforations in the vicinity of major lineations, would have to take place to prove whether an interaction of different ground water bodies takes place along these lineations.

A number of North-South striking lineations in the Western Pampa accord to the direction of the Sierra de Córdoba. The NNW-SSE striking long lineations in the Eastern Pampa are possibly the continuation of faults causing the Rio de la Plata delta.
The "Bajos" and other lineations cannot be connected to wellknown tectonical units.

7. COST SAVING BY THE USE OF ERTS DATA

For conventional reconnaissance mapping of depth to ground water and salinity in the Pampa about 20 observation points at available wells are needed per 100 sqkm.
Large scale mapping for water supply purposes was carried out using about 80 well points per 100 sqkm.
The survey costs per well can be assessed at 30 US $.
With the aid of ERTS imagery in the future the number of observation points for reconnaissance mapping can be reduced by up to 50 % and for large scale mapping by up to 75 %. This equates to a reduction of field costs from 600 $ to 300 $ (reconnaissance mapping), or respectively, from 2400 $ to 600 $ per sqkm (large scale mapping).

8. CONCLUSIONS

Satellite imagery in combination with ground investigations allows the identification and delineation of differences in the conditions of the near surface ground water (depth to ground water, salinity). The degree of precision achieved is greater than that obtainable by conventional ground survey methods alone.

In future it will be possible to produce hydrogeological maps, cheaply and more quickly, of areas with similar climatological and hydrogeological conditions.

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