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UPPSALA UNIVERSITY
DEPARTMENT OF GEOPHYSICS
Section of Solid Earth Physics

Instituto Tecnológico GeoMinero de España

JBA

ENVIRO-MT TECHNOLOGY TRANSFER PROJECT
Contract N° IN100480I

Work package 4: Field testing at end-user demonstration sites & training
Task 4.1.1:

PREDEMONSTRATION DATA PACKAGE FOR THE FIELD TEST SITE OF ALMUÑECAR (GRANADA, SPAIN)1999

Compiled and written by: J. Plata and F. Rubio. ITGE. Spain
version: 1/99

PROYECTO ENVIRO-MT
DOCUMENTO Nº 14b

Instituto Tecnológico GeoMinero de España

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0. ABSTRACT

The proposed area for the field test of the ENVIRO-MT Project is closed to the village of Almuñecar (Granada), in the valley of rio Verde. The aquifer is of alluvial detritus: gravel, sand and silt, laying over a palaeozoic substratum of shales.

Several drilling wells are available in the area, and though some of the geological columns are not very reliable except for the basement depth, they show a great heterogeneity in the distribution of materials within the basin, being necessary to use geophysical methods for their hydrogeological characterisation. The aquifer has several palaeocanals of high permeability, which are the preferential way for the circulation of the water. The increase in the demand for pumping water from the aquifer for agricultural and domestic use during the summer, makes that in drought periods it takes place an intrusion from the sea water, which raises the salinity of the aquifer in a periodic pattern. In spring of 1999, and due to the important rain falling in the last years, it is not expected to have saline intrusion.

Though a complete geophysical coverage was available, some discrepancies between the old VES data and the actual drill holes information, has advice us to make a new geophysical survey in 1998, specially for the purpose of the ENVIRO-MT Project, so that 15 new VES were measured. All the VES curves are of the type KH (conductor- resistive-conductor-resistive). The correlation between resistivities and lithologies were made through parametric measurements close to boreholes, with the conclusion for the area:

* there is a first conductive layer, due to the presence of silty sands, except in the east, where this layer is resistive and due to sand.
* the next resistive layer is due to the presence of gravel and sand, being more thick closer to the actual river bed.
* the following conductive layer is correlated with a group of alternant layers of sand, sandy silt and clay, with gravel in some locations, being the low resistivity probably due to its water content.
* the heterogeneity of the distribution of resistivity is bigger in the east-west direction, keeping the layers a greater homogeneity in a north-south trend.

The map for the thickness of the alluvium shows an increase in depth of the basement to the south.

We propose to make about 300 measurements of ENVIRO-MT, distributed in five profiles, with a total of 3800 m; some tests are also proposed for the analysis of the information; a time table and distribution of operations to be done among the partners is also included.

1. DESCRIPTION AND SITUATION OF THE TEST SITE

The place chosen to test ENVIRO-MT instrument is in the alluvial aquifer system of Almuñecar, on the coast of Granada province (fig.1), southeast of Spain. It belongs to the hydrographic basins of the rivers Verde and Seco, with one extension of 117 km^2 (96 km^2 for river Verde and 21 km^2 for river Seco); the average height of the area is 460 m, from a maximum topographic high of 1700 m in the north, going down to sea level. The village of Almuñecar is situated at 95 km from Granada airport and 90 km from Málaga airport, being accessible by the National motorway N-340 (fig. 2); it has 20.500 permanent inhabitants, and bears a very long history: it started as a human site during the Bronze Age, was a phoenician colony during IX century b.c., roman city from the III century b.c. and arabic from the VIII to XV centuries, being then the main harbour of the Granada kingdom; many archaeological testimonies from all these periods can be found in the actual village (phoenician tombs, roman salted fish factories, arabic castle, etc.). The town is protected from the north winds by Sierra Nevada, and enjoys a microclime with warm winters and mild summers (the average temperature ranges between 18° C and 25°C), with more than 320 sunny days in the year.

Nowadays it is a tourist resort centre, what makes its population grow up to more than 100.000 inhabitants during the summer season; nevertheless it keeps its tradition as a fish and agricultural village, growing in its river valleys the most important production of tropical fruits of the Iberian Peninsula. In particular, in the valley of rio Verde there is a very important plantation of chirimoya and avocado trees; this trees, specially the chirimoya ones, are very leafy, spreading its branches to less than one meter from the ground and touching a tree with the next one, what makes the plantations nearly impenetrable until gathering time, which takes place in winter, until the end of february, when the trees start to lose its leaves, that grow again for september. The village uses the water from the closest part of the aquifer for urban and agricultural needs. During drought years, and due to the important increase in the demand of water during the summer, the sea water intrudes part of the aquifer, following a way or path which is marked by the irregular distribution of the permeability; because of the great importance that this aquifer has for the economy of the region, a lot of studies of the aquifer have been undertaken along many years, to know in detail its morphology and to be able to control adequately the unwanted effects of sea water intrusion, which by now, draws back during rainy periods.

The area proposed for the test is closer than 500 m from the village; the only open sites are two rural roads running from south to north: "Camino de la Vega primero y segundo" (fig. 2), and the river Verde bed, being the rest of the surface of the valley covered by the plantations of tropical trees (see pictures attached).

2. PROBLEM TO BE INVESTIGATED

The survey to be done in this site fulfils the tasks planned in Work Package 4 of the Project, in what concerns the field testing of the method and the training for the end users partners personnel, and Work Package 6 for the demonstration and dissemination activities of the Project for the interested people from the Geophysics european industry (Observers Group).

The specific hydrogeological objectives to achieve with this test are:

- Determination of the morphology of the aquifer under the proposed area.
- Detection of the sea water intrusion zone, in case it exists at the time.
- To evaluate the general behaviour of the instrument and ENVIRO-MT methodology.

3. GEOLOGICAL INFORMATION

The area of Almuñecar is located in the inner zone of the Cordilleras Béticas, belonging to the Alpujarrides Complex (Fig.3), which is characterized by an overthrust tectonic, formed by several units with different degree of metamorphism. In our zone we have the "Manto de Salobreña" unit covering most part of the area (legend numbers 14 to 21) with a Palaeozoic layer of micaschist and quartzite, and a marble Triassic layer (20) which is outcropping to the north of Jete, and the "Manto de la Herradura" unit, which outcrops in the south (numbers 3 to 13), with a Palaeozoic layer of schist and a Triassic marble layer which arises in the northern coast of Almuñecar. Over this substratum we found postorogenic materials, generally detritic ones, of alluvial character (gravel, sands and sills), on the river valleys. Over the test area Quaternary gravels and sands covers the Palaeozoic part of both units (numbers 14, 17 ?, 7 and 8).

In the map position of fig. 4 are indicated the drilling boreholes existing in the area, being some of them used as pumping wells and others just as piezometers. They are identified by a number, which is related to its situation in the Topographic Sheet at the 1/50.000 scale, but in some instances there is a second number (due to a previous system of identification, reference CASE), which is the only one used in some old documents of the area. The differences in time in which the drillholes have been done, makes that the geological information supplied (in some cases it is just the description given by the driller) does not follow an homogenous criterium, what puts some difficulty to make correlations.

Simplifying the different criterium used in the original data, in fig. 6 two schematic geological profiles of the valley is given (their situation in indicated in fig. 4 and the old identification number for the holes are used), showing the main granulometric distribution of materials throughout the whole area: though fine grained materials are more abundant to the south, there are some intercalations of layers with coarse grained lithologies, which may be old paleochannels, and which will suppose preferential ways for the sea water intrusion. In fig. 7 the thickness of the aquifer is represented; the course of the river as well as the changes in the dip of the substratum may be due to tectonic accidents; the actual river bed does not coincide with the maximum thickness area.

In fig. 8 the columns of the boreholes in the area of the rio Verde valley proposed for the ENVIRO-MT test are situated in its place; it is very difficult with this kind of data to make a geological correlation because of the lateral heterogeneities found, being then essential to use geophysical methods to characterize the layers and to define the geometry of the aquifer.

4. HYDROGEOLOGY

The aquifer of rio Verde has an extension of 3.7 km^2 from Jete to the coast (fig. 3); its width varies from 100 m in the north, 900 m in the centre of the valley and 350 m by the coast; in most of its extension it is a free or semiconfined aquifer, and independent from the rio Seco aquifer. It is constituted by alluvial sediments over palaeozoic materials, with paleochannels (fig. 11) which existence is confirm by hydrodynamic and hydrochemical observations and are preferential ways for the circulation of the water.

The recharge of the alluvial aquifer is due to the following mechanism:

- Direct surface infiltration from the rain falls.
- Infiltration from the runoff, characterized by a big increase, of short duration, immediately after the rain fall.
- Recharge coming from the drainage of the head aquifers, with a rather constant flowrate.

The direct and runoff infiltration are more important besides Jete, where the alluvial is better developed.

Most of the volume of water is taken out from the central portion of the aquifer, by means of wells and boreholes, and is used mainly for irrigation, though the 34.6 % (in 1987) is for domestic use. The increase in the demand for water coincides both for agricultural and domestic use from may to september, what provokes the sea water intrusion; fig. 12 shows the time variation of the water chloride content, and fig. 13 shows the spacial distribution of the chloride concentration in 1982.

The thickness of sediments (fig. 7) increases to the coast, being more than 60 m just in one small strip parallel to the rainfed watercourse. From the studies of the aquifer permeability it is known that the effective porosity is of the order of 18 % to 21 % near Almuñecar, and decreasing to the north down to the 13 %; the horizontal permeability in m/day is very heterogenous, with two areas: one with values between 15 m/day and 67 m/day, and the other with values between 136 m/day and 461 m/day, geographically distributed following the probable paleochannels of rio Verde.

5. PREVIOUS GEOPHYSICAL INVESTIGATIONS

During 1977 a VES survey was made, covering all the surface of the rio Verde valley shown in fig. 2; the general distribution of resistivities found was: a first silt conductive layer, between 40-80 ohm m and less than 10 m thick covers all the valley; beneath it there is a more resistive detritic layer, with 150-300-450 ohm m, which thickness increases to the coast from 10 m to 30-40 m, and follows the morphology of the basement; a third detritic and less resistive layer of more fine grained material is situated under the last one, with values ranging from 65-360 ohm m, and a homogenous thickness of about 40 m (after the VES survey interpretation); this layer wedges itself before reaching the coast, what allows the deposition of a conductive layer before the substratum in this portion of the area; the last layer is the resistive palaeozoic rock. In general the resistivity decreases in all the layers as one gets closer to the coast, which may be interpreted as a decrease in the grain size of the detritic materials. This situation reflects very approximately the geological profile given in fig. 6, but there is rather important local discrepancies with the thickness of alluvial materials found in the mechanical drillings, many of them made after the geophysical survey. As field data are not available for reinterpretation, a new VES survey has been made in 1998, in order to confirm the resistivities distribution in the area proposed for the ENVIRO-MT field test.

5.1 NEW GEOPHYSICAL VES SURVEY IN 1998

New 15 VES have been measured by ITGE in june of 1998, in the position shown in fig. 20. A Schlumberger array with AB distance between 400 m and 900 m has been used to reach the substratum. Readings have been taken with a Syscal (IRIS Instruments) resistivity meter, using impolarizable potential electrodes and iron sticks as current electrodes. Inversion of the data has been carried out with the semiautomatic interpretation software RESIXIP (Interpex Ltd.).

In fig. 21 all the VES curves are shown; its morphology is very similar, of the KH type; they have been grouped in four kinds or families, which geographical distribution can be seen in fig. 20; the first family is formed by VES 11 and 14, to the west of the valley; the second one is constituted by VES 12, 13, 43 and 24, in the south central-western portion of the area; to the east are located the two other families, grouped also in trenches parallel to the river: the central one is formed by VES 15, 41, 21, 22 and 23, and the more eastern one by VES 31, 32, 33 and 42. The pattern of this distribution shows a variation of resistivities in a west-east trend, increasing the resistivity values the closer we are to the actual river bed, and being the layers more homogeneous in the north-south direction.

Some of the new VES have been measured very close to a mechanical drilling, in order to get a tight correspondence between resistivity values and lithology; the result is given in fig. 22.

Borehole 7-71 and VES 11 have been taken as the reference for the rest of the VES interpretation: the first conductive layer of 29 ohm m is due to the presence of silty sands. Next resistive layer of 84 ohm m corresponds to gravels; the conductive layer of 10 ohm m is due to a sequence of silty sands, silt and clay at the bottom of the hole, before reaching the resistive palaeozoic shales. Keeping this sequence for the rest of the parametric VES, the general situation for the area may be established:

The first conductive layer, from 29-45 ohm m, marks the presence of silty sands or sandy silts in holes 7-71 and 7-76, but in hole 7-74 this resistivities correlate with a layer of sand and partially of gravel; in drills 7-46, 7-73 and 7-77 to the east, the first layer is no longer conductive in parametric VES 23, 31 and 33 respectively, and corresponds to a sand and gravel layer, except in 7-73 where it corresponds to silty sands.

The next layer is more resistive, varying from 84 ohm m to 464 ohm m, and is thicker to the east; it corresponds to gravels, sand and conglomerates.

The following conductive layer, from 10 ohm m to 49 ohm m, correlates with an alternance of sand, silty sand, silt and clay, except in hole 7-46 where there are conglomerates.

The last resistive layer, from 133 ohm m to 500 ohm m, corresponds in all cases to the shales substratum, being the thickness of the alluvial given by the VES interpretation and by the boreholes in a very good correlation.

The result of this interpretation gives a correlation between the resistivity values and the lithology which may be classified as follows (numbers are ohm m):

. sandy silt (arenas con limo o limosas): 45
. silty sand (limos arenosos): 29,10,49,36
. sand (arena): 37,31,400,464
. gravel, gravel+sand, conglomerates(?)
  (gravas, arenas con bolos, conglomerados): 84,64,93,274,36
. coarse grained sands: 35
. shale (pizarras): 511,214,206,133,273

One conclusion of this correlation is that the resistivity values are representing rather variations in the water content and/or temperature of the layers, with some independence of their lithology, with clear anomalous values (mainly in the sandy layers), probably due to a poor description of the drillholes geological columns.

Several geoelectrical profiles, with the situation indicated in fig. 20, have been drawn with the interpretation of the new VES, showing the distribution of resistivities in the test area. In the geoelectrical profiles of fig. 23 and 24 there have being included the geological columns of the boreholes. Profile 1, from north to south, shows a first conductive layer of silty sands, thicker in VES 11, with a thin resistive intercalation; the resistive gravels layer has a thickness of about 10 m, and is also deeper in VES 11; the next resistive layer is 20 m to 30 m thick, and it is due to a variety of lithologies (silty sand, silt and clay).

A similar distribution is present in profiles 2 and 3 of the same direction, though in both it is more clear the increase in thickness for the last conductive layer to the south. In profile 3, the most eastern one, the resistive intercalation in the upper portion of the underground is thicker, reaching up to 10 m. The difference in the resistivity of the first resistive layer among the three north- south profiles could be interpreted as a difference in the grain size of the alluvium deposits or in the water content.

Profiles 4, 5, 6 and 7 have an east-west trend, and show a growth in the thickness of the resistive layer towards the actual river bed, while the shallow conductive layer decreases and even disappear in some locations.

Fig. 25 shows the thickness of the aquifer upon the information of the VES and drilling holes, and because of the nearly flat topography, is it also a picture of the geometry of the top of the substratum. Several methods of interpolation of data have been used, as well as several methods of colouring representation of the results; minimum curvature gives a softer looking, while the result for triangulation reminds more the trend of paleocanals in fig. 7; any way, it can be appreciated that the basin is thicker to the south.

5.2 RESISTIVITY AND I.P. PSEUDOSECTION

A resistivity and IP continuous profile has also been measured in june of 1998, using an Elrec receiver and an Electra as transmitter, both from IRIS Instruments, what allows to measure up to six simultaneous points, with a dipole-dipole electrodes arrangement. A distance of 50 m has been used between measurement points, with a maximum distance between centre of dipoles of 300 m, with the intention of reaching at least a depth of 70 m.

The profile runs north-shout and its position is indicated in fig. 20; field measurements are shown in fig. 26; data have been processed with RES2DINV v 3.3 software, and the interpretation is given in fig. 27, where it is shown the apparent resistivity pseudosection, the interpreted model and the calculated pseudosection. Unfortunately, the penetration has been too deep, and the resolution not as good as expected. The general trend in the distribution of resistivities is similar to the one shown in VES profile 1, with a conductive layer with some discontinuities, and an increase of resistivity versus depth; the layers are dipping to the south, though the impression in the section is the opposite due to the topography. The values of the resistivity are nevertheless rather different from those obtained by VES, mainly for the substratum.

6. PLANNING OF THE ENVIRO-MT TEST SURVEY

6.1 Profiles proposed and time required for the field work

Three transversal profiles P1, P2 and P3 of about 600 m each and two longitudinal profiles P4 and P5 of 1000 m each are proposed to be measured in Almuñecar test site, in the position shown in fig. 29.

- The average production rate estimated is of 10 readings per hour; the time then required for the grid to be measured is:

. 3 transverse profiles of 600 m each, with readings every 10 m:

60 readings/profile = 6 h/profile

. 2 longitudinal profiles of 1000 m each, with readings every 15 m:

67 readings/profile = 7 h/profile

That makes a total of 3800 m of profiles, with 314 stations, with an estimated time for the field work of 32 h (equivalent to 5 days).

- Transmitter antenna is install daily; time required 45 min.

6.2 Support given by ITGE:

- one Senior Geophysicist during all the time of the test.
- two field helpers during the full time of the field test.
- wood sticks to mark the reading stations position.
- one all terrain vehicle.
- auxiliary material: metric tapes, ropes, etc.

6.3 Operations to be done in the field by ITGE personnel:

- to obtain all the permissions necessary prior to commencement of the survey

- setting and gathering of the transmitter antenna daily
- full assistance for the displacement through the profiles of the electrodes and magnetometer
- partial assistance in the operation of readings with the receiver

6.4 Operations to be done by JBA personnel in the field:

- general support for the field test, Project Meeting and training sessions requirements.
- main responsible for the organization, necessary arrangements for accommodation, and local attention to the observer group activities.
- setting of the sticks on the profiles and topographical survey of the stations.

6.5 Operations to be done by Metronix and Uppsala personnel:

- Transport of the instrumentation to and from the field test site
- Main responsible for the handle and reading of the transmitter and receiver
- To keep and maintain all the documents got during the test

6.6 Documentation to be taken during the field tests:

- a diary of the operations
- documented files with field data
- paper presentation of the field measurements
- geoelectric sections

6.7 Description of the tests to be done:

1/ TEST FOR THE GENERAL GEOLOGICAL EVALUATION OF THE SYSTEM

This Test tries to evaluate if the system is really giving geological information with the expected level of precision, quality and resolution.

. It will consists of the full set of ENVIRO-MT measurements to be taken on the three transversal profiles (P1, P2 and P3) and the two longitudinal ones (P4 and P5), which position is indicated in fig. 29; the results will be compared with the geological information previously available from the VES survey and mechanical drillings, being its objective to determine the geometry of the aquifer (thickness, extension, and nature of the different layers, mainly of the sand-gravel ones), as well as the morphology of the substratum.

2/ TEST OF COMPARISON WITH THE RESISTIVITY PSEUDOSECTION

. It consists in the measurement of one ENVIRO-MT profile (P4 in fig. 29) with readings every 15 m, parallel to the profile previously taken with cc and a dipole-dipole array of 50 m - 300 m every 50 m. Quality of the information obtained will be compared, as well as the time required in the field work with both methods and the difficulties found with each operative system.

3/ REPEATABILITY TEST

. It will consists in reading twice one of the transversal profiles (P1, P2 or P3), with the same reading parameters, to compare the results with statistical support.

4/ PRODUCTIVITY TEST

. It consists in measuring twice the same transversal profile, with the same recording parameters, but following two different operational systems: first time with one receiver operator and two helpers for the displacement of the instrument by the profile, and the second one with just one helper. During both sessions of readings, field personnel must not be disturb by any visit, so that the rhythm of the operation be representative of actual conditions in one industrial survey. This test will be done at the same time as the repeatability test.

5/ VERTICAL RESOLUTION TEST

. It consists in doing a set of ENVIRO-MT measurement close to a selected mechanical drilling borehole, using several ranges of frequencies, so that its influence in the vertical resolution achieved and in the time taken to do the measurements could be evaluated.

6/ HORIZONTAL RESOLUTION TEST

. Once several profiles have been measured, a zone of 50 m with important lateral changes will be selected. The test consists in taking new readings on this zone, with a distance of 5 m between them.

7/ DIRECTIONALITY TEST

. An area will be selected, in which the geology shows a great lateral homogeneity (no significative lateral changes), and preferably close to a borehole; 4 short profiles with a common central point and orientations every 45 °, of 50 m each, will be measured with an interval of 10 m between readings. Results will be compared, to evaluate the effect of the direction of the profiles over the distribution of resistivities obtained.

8/ TRANSMITTER POSITION DEPENDENCE TEST

. It consists in measuring a portion (100 m) of the same profile with the transmitter located in two different directions making 90 °.

9/ SENSIBILITY TEST

In an homogeneous area, at least 5 stations will be repeated, modifying within "tolerable" limits the distance between electrodes, the orientation and levelling of the magnetometer, and replacing the electrodes sticks by ordinary steel sticks.

6.8 Situation of the transmitter

For a distance between receiver and transmitter of the order of four times the skin depth ($500\sqrt{\rho}/\phi$), we have for the resistivities found in the area:

	f (frecuency)	
ro (resistivity)	1000 Hz	300 Hz
300 ohm.m	1100 m	650 m
40 ohm.m	400 m	240 m

In fig. 29 two possible initial positions for the antenna are indicated.

6.9 Tests timetable:

April 1999:

Mo 12 Arrival in Almuñecar.
Tu 13 Visit to the zone; to decide the location for the transmitter;
to verify the right working of the instruments. Test 5.
We 14 Training Session. Survey of profile P1
The 15 Survey of profile P2
Fr 16 Repetition of survey of profile P1: test 3 and test 4
Sa 17
Su 18
Mo 19 Project Meeting. Survey of profile P4; test 2
Tu 20 Test 6, test 7, test 8, test 9. To attend visitors.
We 21 Survey of profile P3. To attend visitors.
The 22 Survey of profile P5. To attend visitors.
Fr 23 Spare time; compilation of results.
Sa 24
Su 25

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FIGURES

Note: figures in this report do not have a consecutive identification number; all of them are taken from reference ITGE 1998, keeping in this Report the same number as in the original.

WARMING

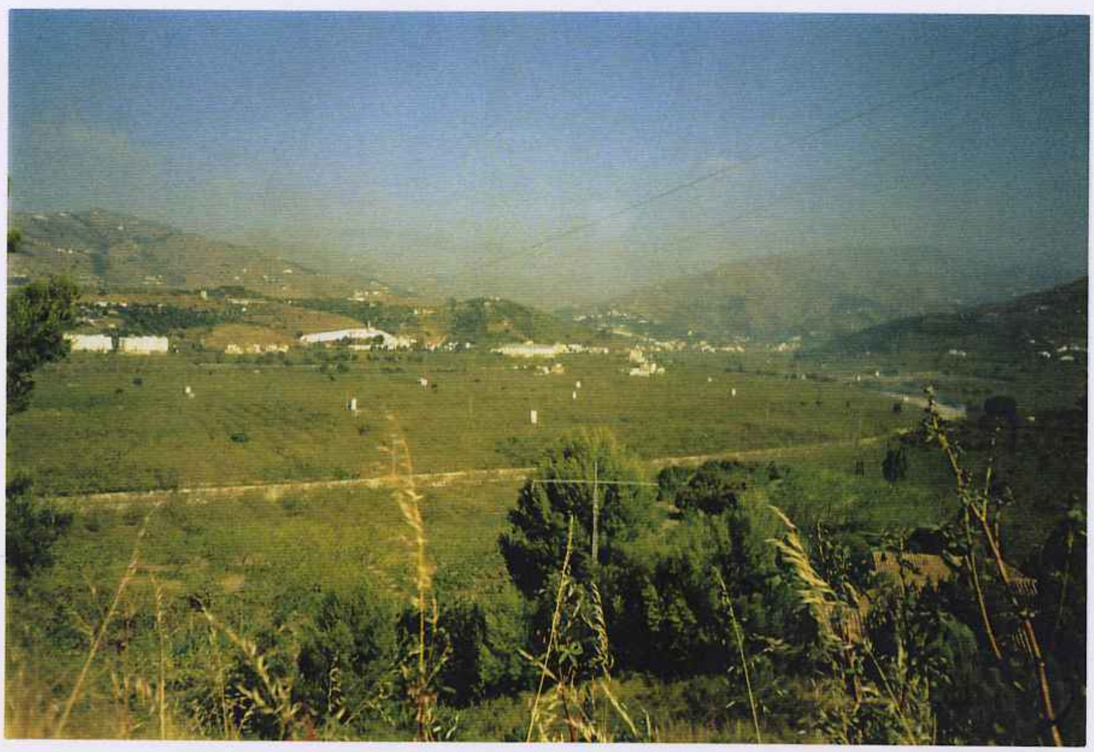
AFTER EDITING OF THIS REPORT AN ERROR HAS BEEN DETECTED IN THE DESCRIPTION OF THE GEOLOGY OF BOREHOLE 7-74 IN FIGURES 8, 22, 23 Y 24; THE ACTUAL GEOLOGICAL DATA ARE THE FOLLOWING ONES:

0-1 m: gravas con arcillas (gravel and clay)
1-8 m: arcillas (clay)
8-10 m: arena media (medium sands)
10-18 m: gravas (gravel)
18-22 m: arenas medias (medium sands)
22-30 m: gravas (gravel)
30-42 m: limos (silt)
42-43.5 m: esquistos (schists)

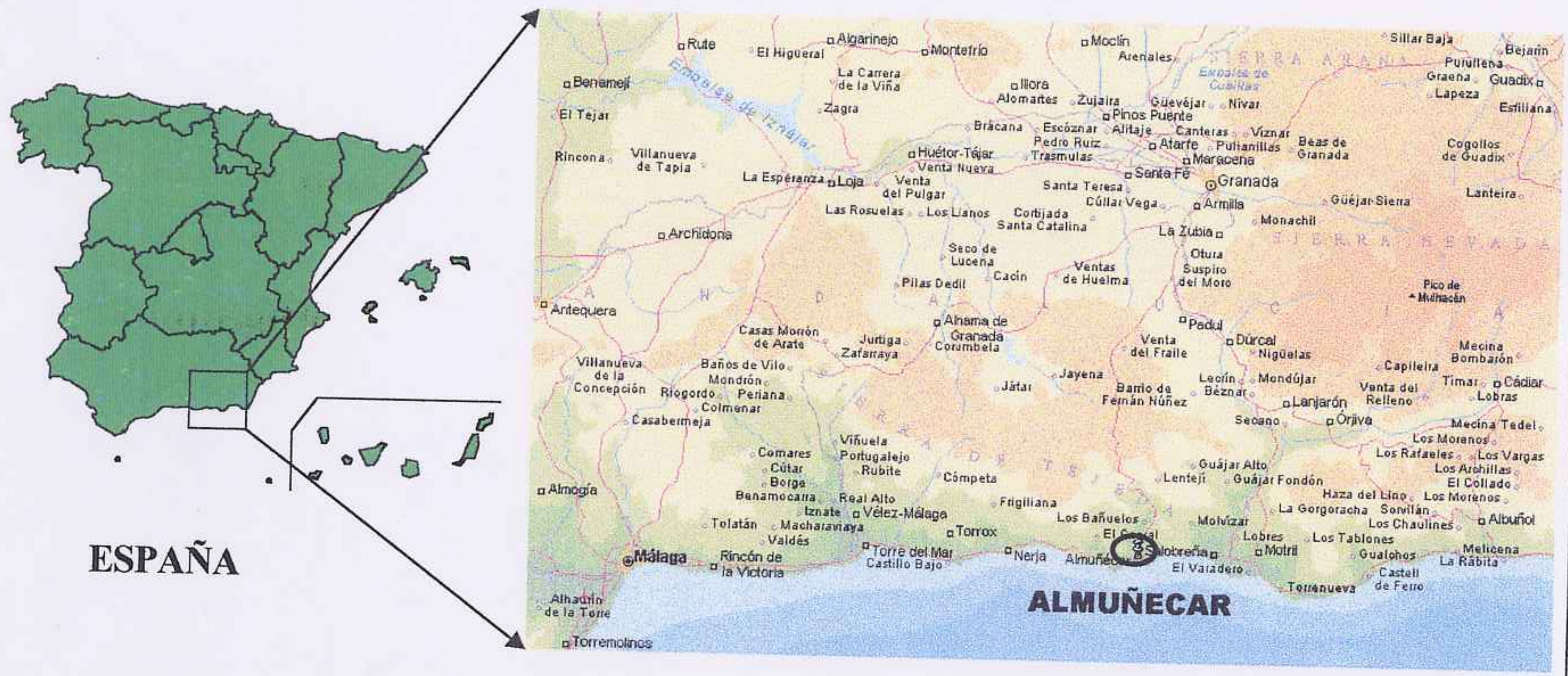
THIS ERROR IS ALREADY CORRECTED IN FIGURES 6 AND 7 IN THE "REPORT ON THE INTERPRETATION OF ENVIRO-MT DATA FROM TEST SITE OF ALMUÑECAR (SPAIN).1999.

Some views of the chirimoya plantation in june

Aspect of the "Camino de la Vega primera"

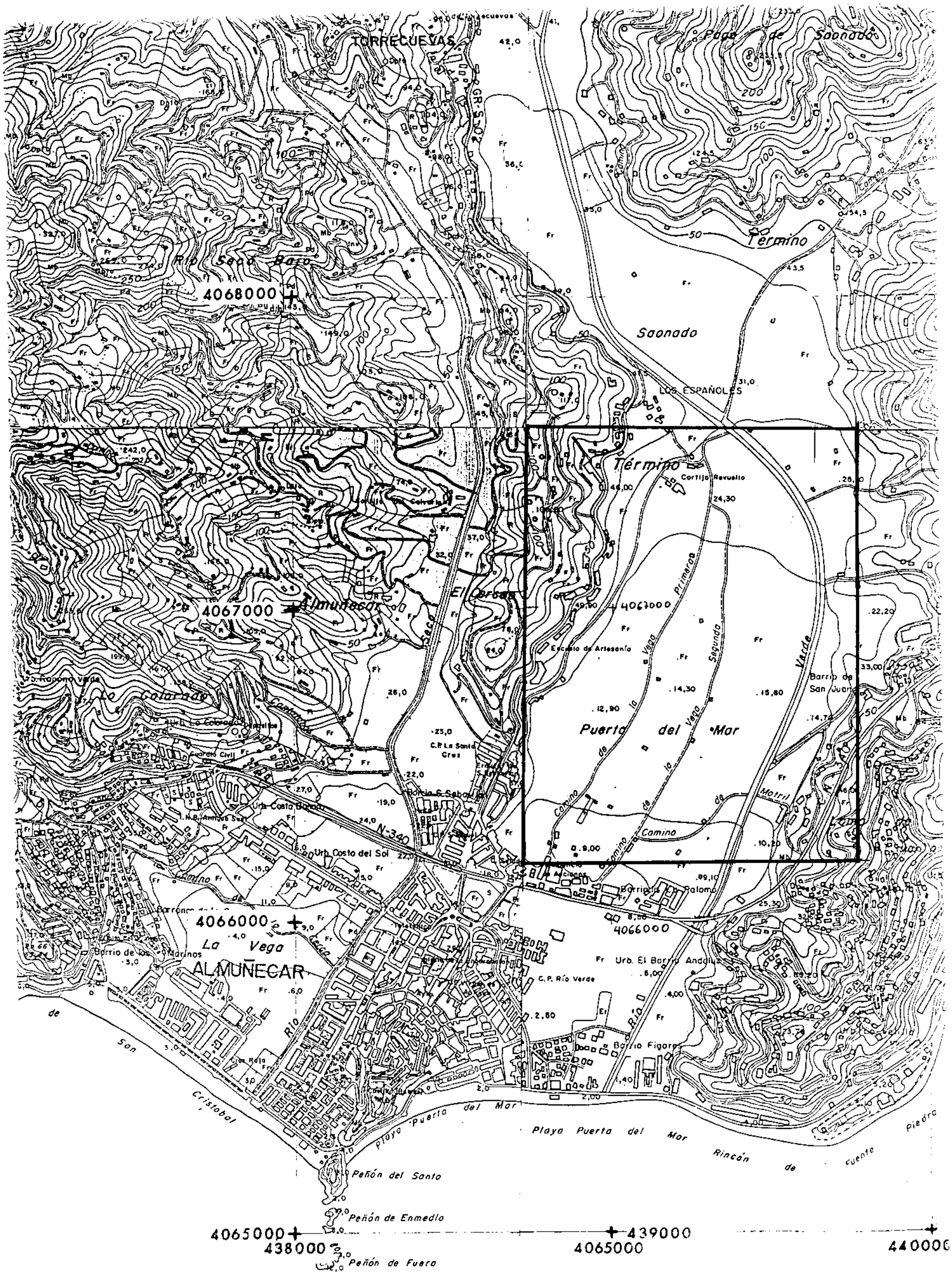


View of the test area taken from road N-340, looking to the North and North-west



DETALLE AREA DE GRANADA

FIGURA 1

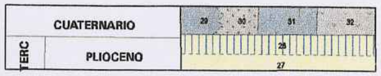


ZONA DE ESTUDIO

Fig. 2

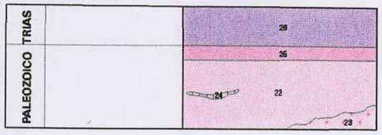
Instituto Tecnológico GeoMinero de España

LEYENDA

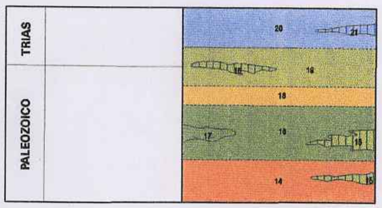


32 Derrubios.
31 Travertinos.
30 Arenas de playa.
29 Gravas y arenas.
28 Conglomerados y limos rosados.
27 Arenas amarillas. Limos y conglomerados sueltos.
26 Mármoles frecuentemente con biotita.
25 Cuarcitas de tonos rojizos.
24 Mármoles intercalados.
23 Migmatitas y gneises migmatíticos.
22 Esquistos negros grafitosos con sillimanita y distena.
21 Calcoesquistos intercalados.
20 Mármoles con tremolita.
19 Esquistos de grano fino con clorita y biotita.
18 Cuarcitas con granate y eventualmente estaurolita.
17 Cuarcitas y cuarzoesquistos con estaurolita.
16 Esquistos oscuros y cuarcitas con estaurolita y en su base distena.
15 Mármoles intercalados.
14 Esquistos oscuros y cuarcitas con estaurolita, sillimanita y distena.
13 Esquistos intercalados.
12 Mármoles con intercalaciones esquistosas.
11 Mármoles intercalados.
10 Esquistos con biotita, clorita y epidota.
9 Esquistos grises con biotita y hacia la parte inferior granate.
8 Esquistos grises biotíticos con estaurolita: en la unidad del Jate, distena en la parte inferior.
7 Esquistos con sillimanita. Cuarzoesquistos, anfibolitas y epidotas.
6 Mármoles intercalados.
5 Esquistos y cuarzoesquistos oscuros con estaurolita.
4 Cuarcitas y esquistos oscuros con sillimanita y feldespato potásico.
3 Migmatitas y gneises migmatíticos.
2 Dolomías, calizas y mármoles.
1 Filitas y cuarcitas. Calcoesquistos.

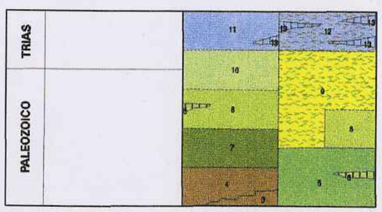
(MANTOS) ALPUJARRIDES
MANTO DE LOS GUAJARES (UNIDAD DE GUINDALERA)



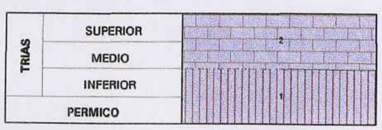
UNIDADES DEL MANTO DE SALOBREÑA



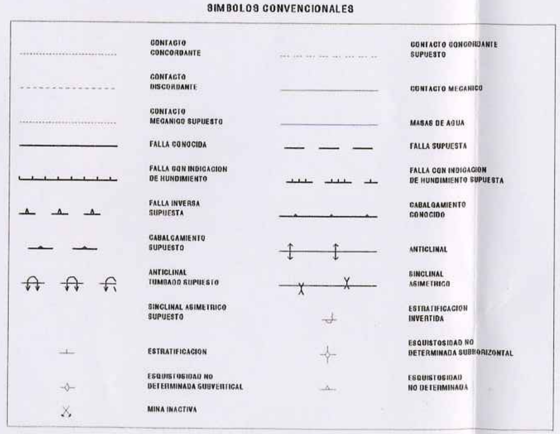
UNIDADES DEL MANTO DE LA HERRADURA



MANTO DE ALCAZAR



SIMBOLOS CONVENCIONALES



MAPA GEOLOGICO DE ESPAÑA
ESCALA 1:50.000 ZONA DE ALMUÑECAR

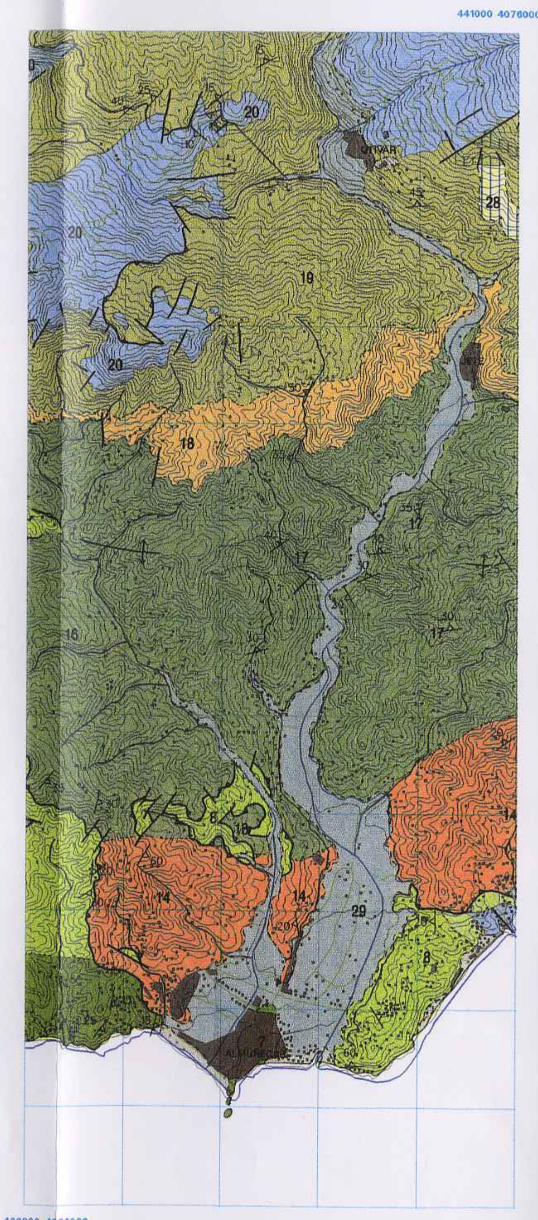
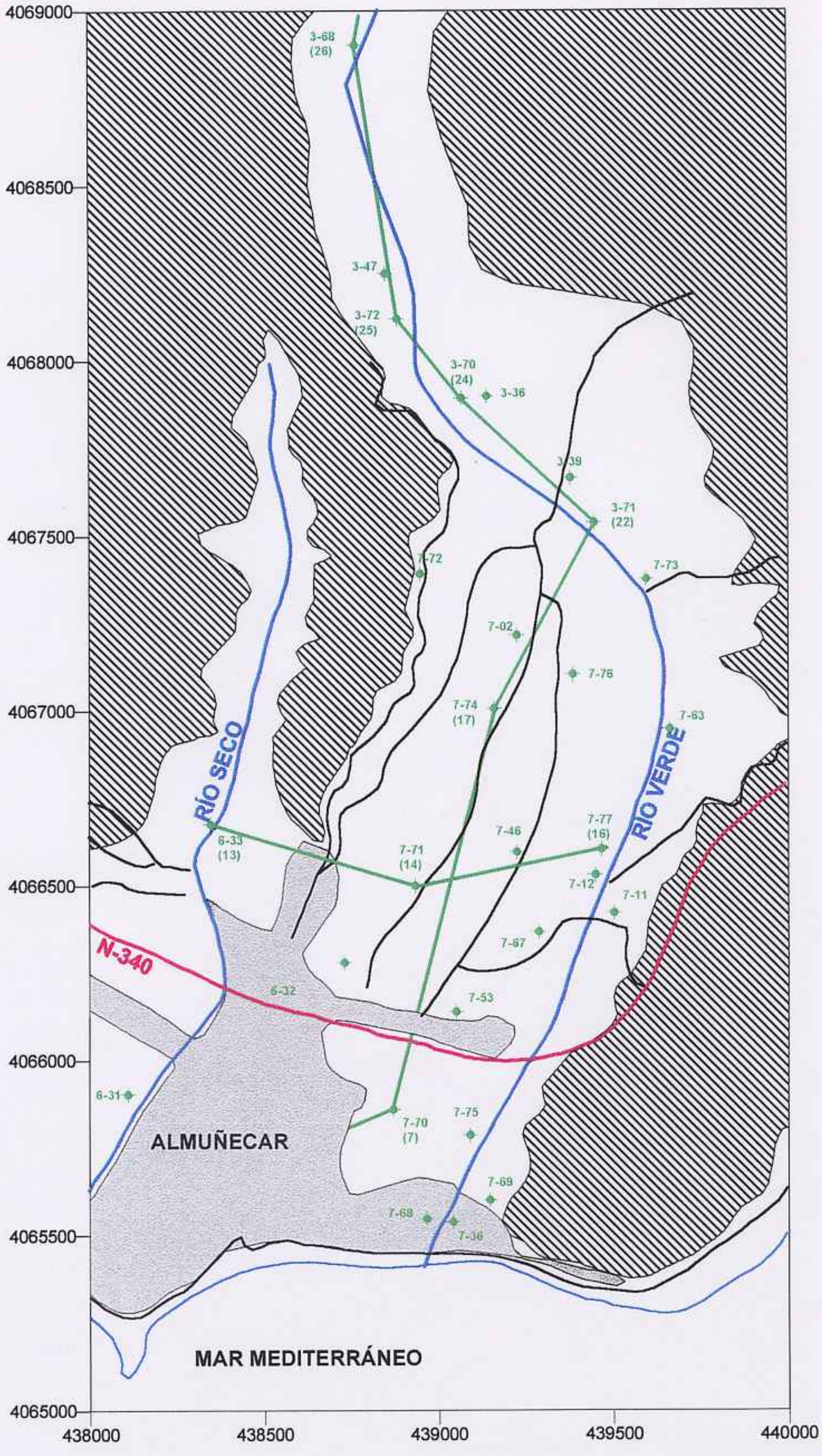


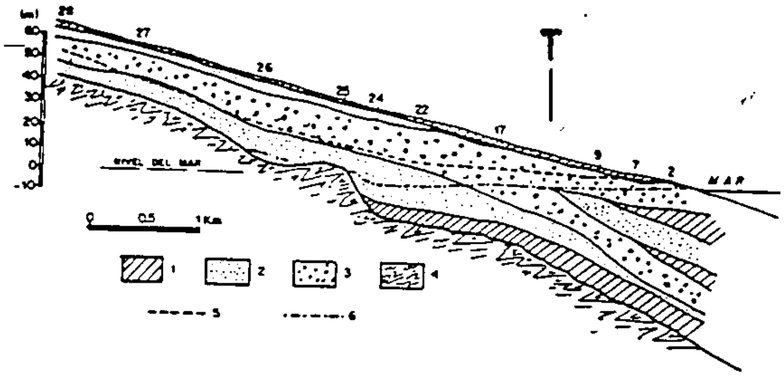
Figura 3.

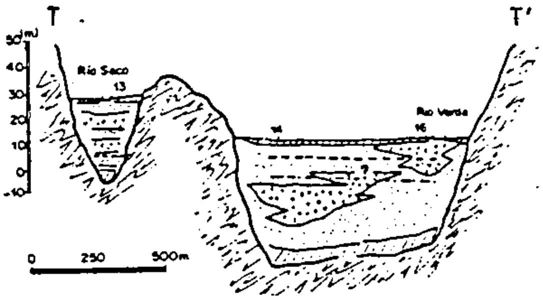


Sondeo mecánico (7-068 referencia base datos ITGE; (17) referencia CASE)

Perfil correlación de sondeos figura 6

FIGURA 4





1 Materiales con predominio de limos y arenas finas
2 Arenas medias predominantes
3 Arenas gruesas y gravas
4 Substrato metapelítico
5 Nivel piezométrico en aguas altas
6 Nivel piezométrico en estiaje

FIGURA 6. Cortes hidrogeológicos esquemáticos. Los números representan sondeos de la CASE. (Calveche y Benavente, 1988)

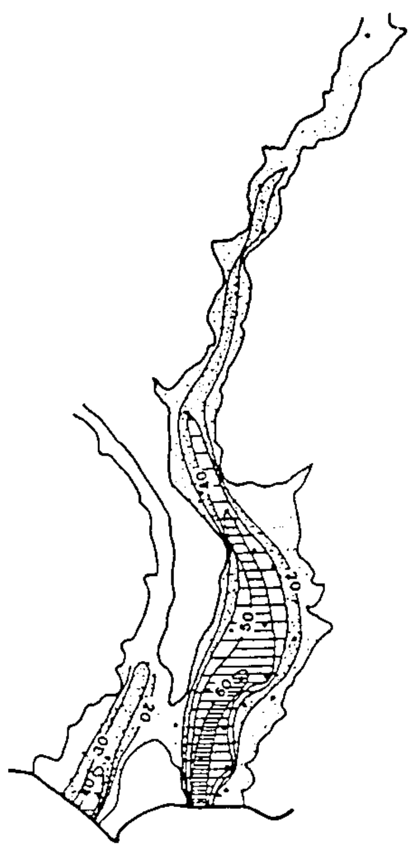


FIGURA 7. Estimación de los espesores del acuífero en metros. (Calveche y Benavente, 1988)

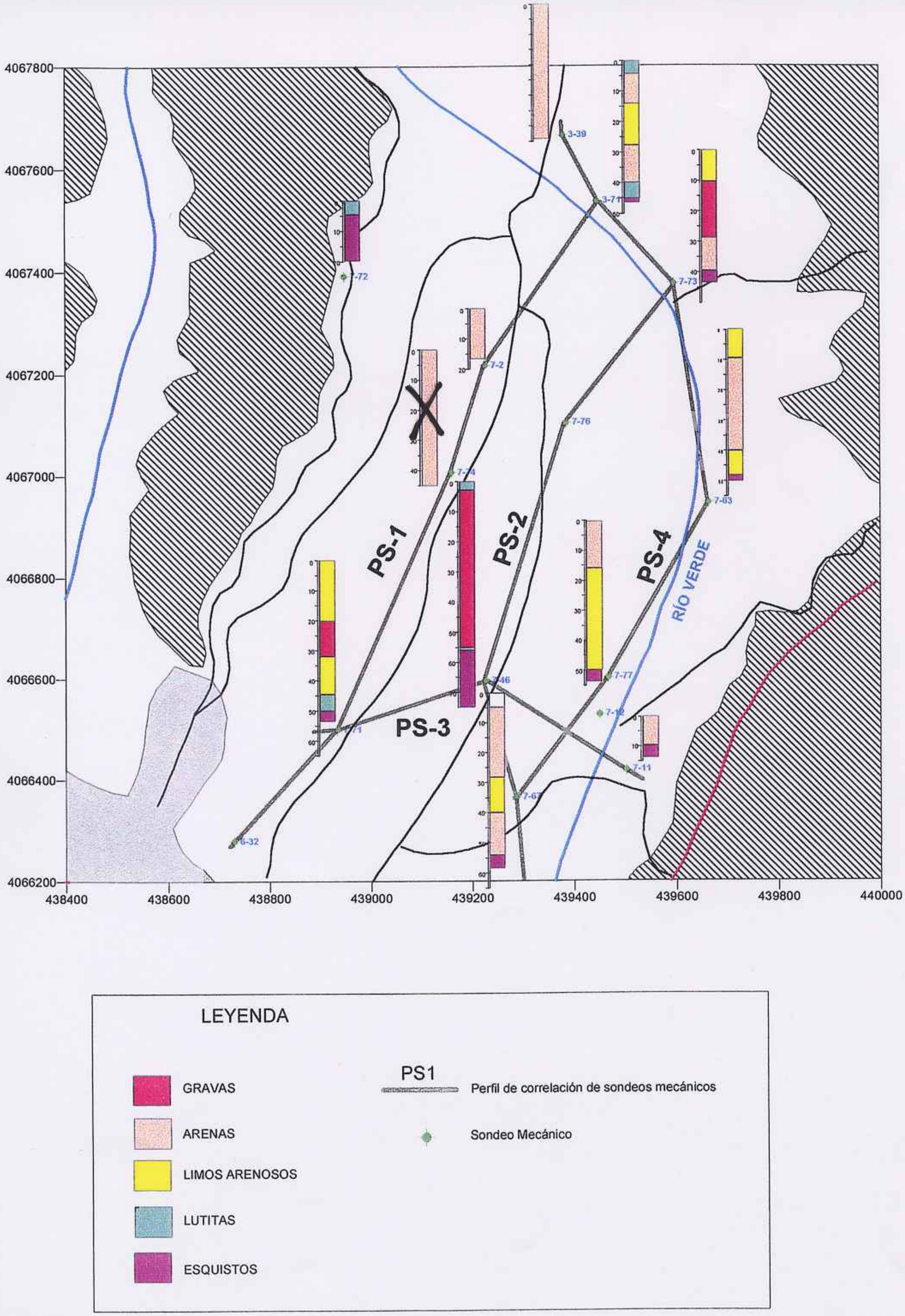

4067800
4067600
4067400
4067200
4067000
4066800
4066600
4066400
4066200
438400
438600
438800
439000
439200
439400
439600
439800
440000
PS-1
PS-2
PS-3
PS-4
RÍO VERDE
3-39
7-72
7-73
7-2
7-76
7-77
7-11
LEYENDA
GRAVAS
ARENAS
LIMOS ARENOSOS
LUTITAS
ESQUISTOS
PS1
Perfil de correlación de sondeos mecánicos
Sondeo Mecánico

FIGURA 8

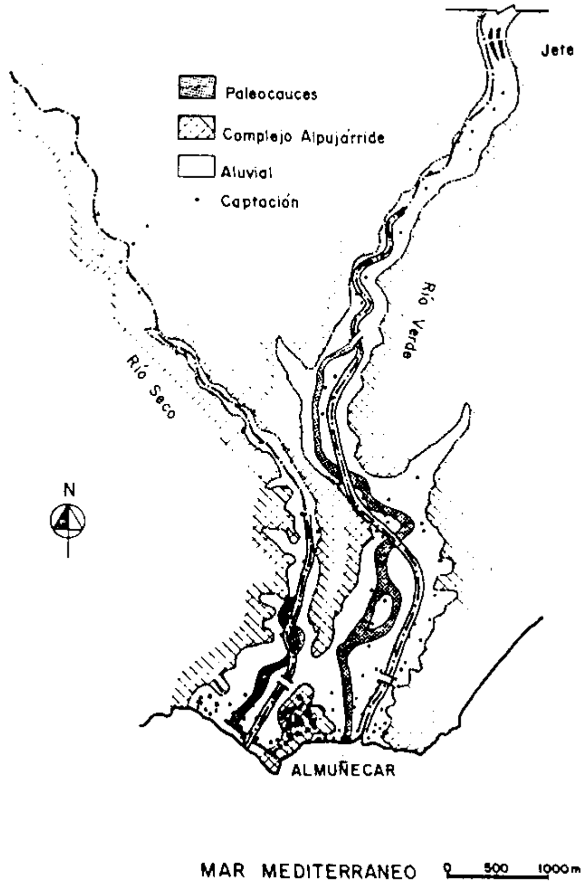


FIGURA 11. Paleocauces en el acuifero aluvial de Almuñecar.

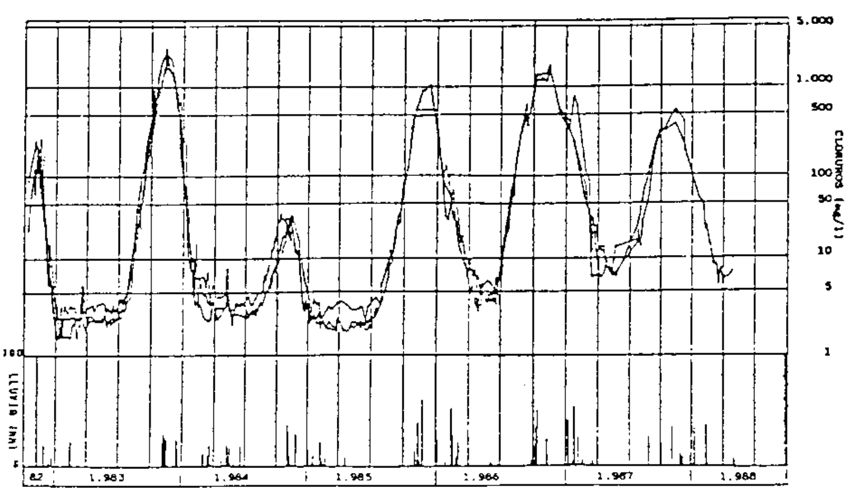
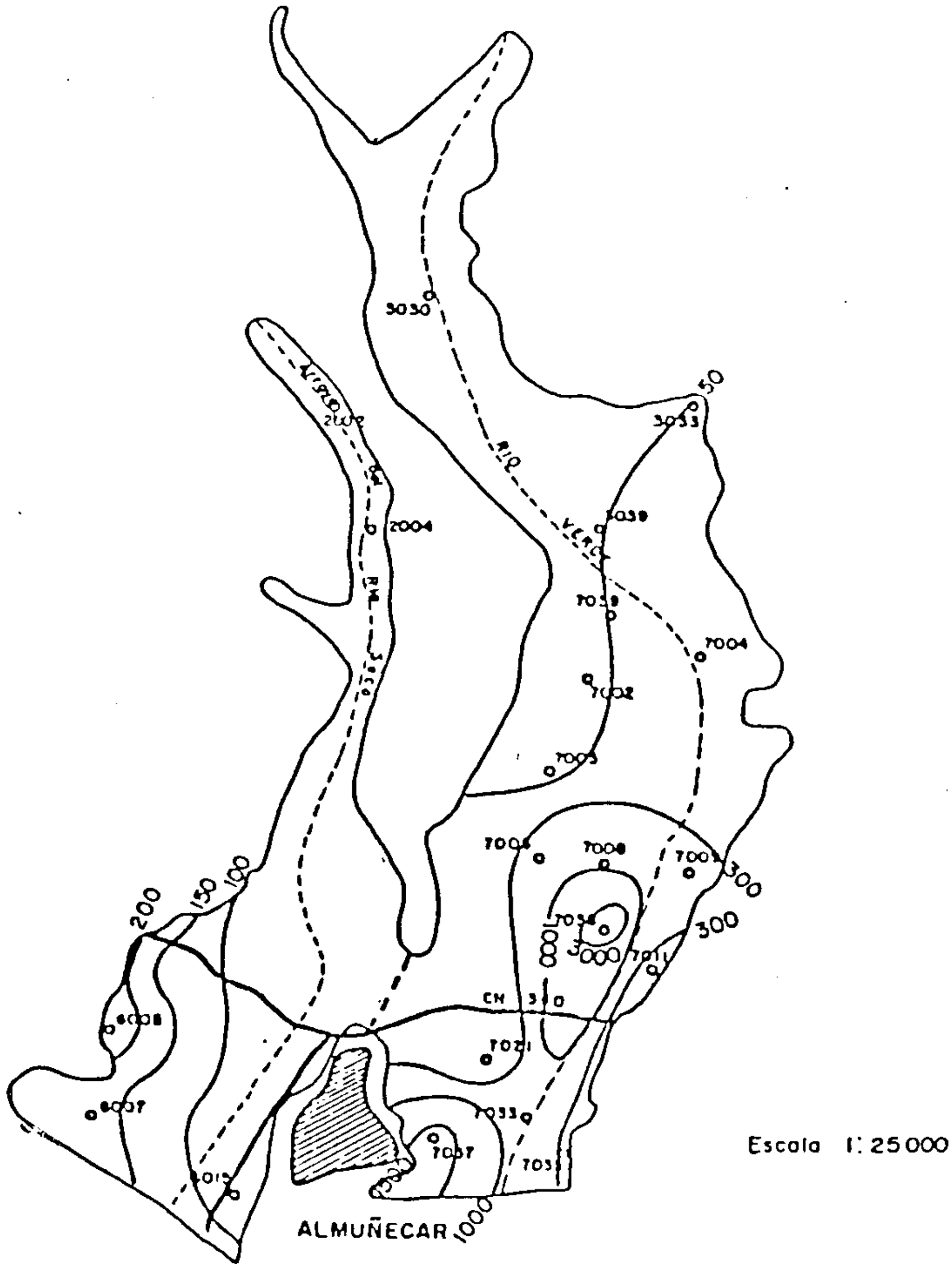


FIGURA 12. Variación, a lo largo del tiempo, del contenido de clururos en los sondeos de abastecimiento de Almuñecar (expresado en escala semilogarítmica). (Fernandez-Rubio y Tacón, 1988)

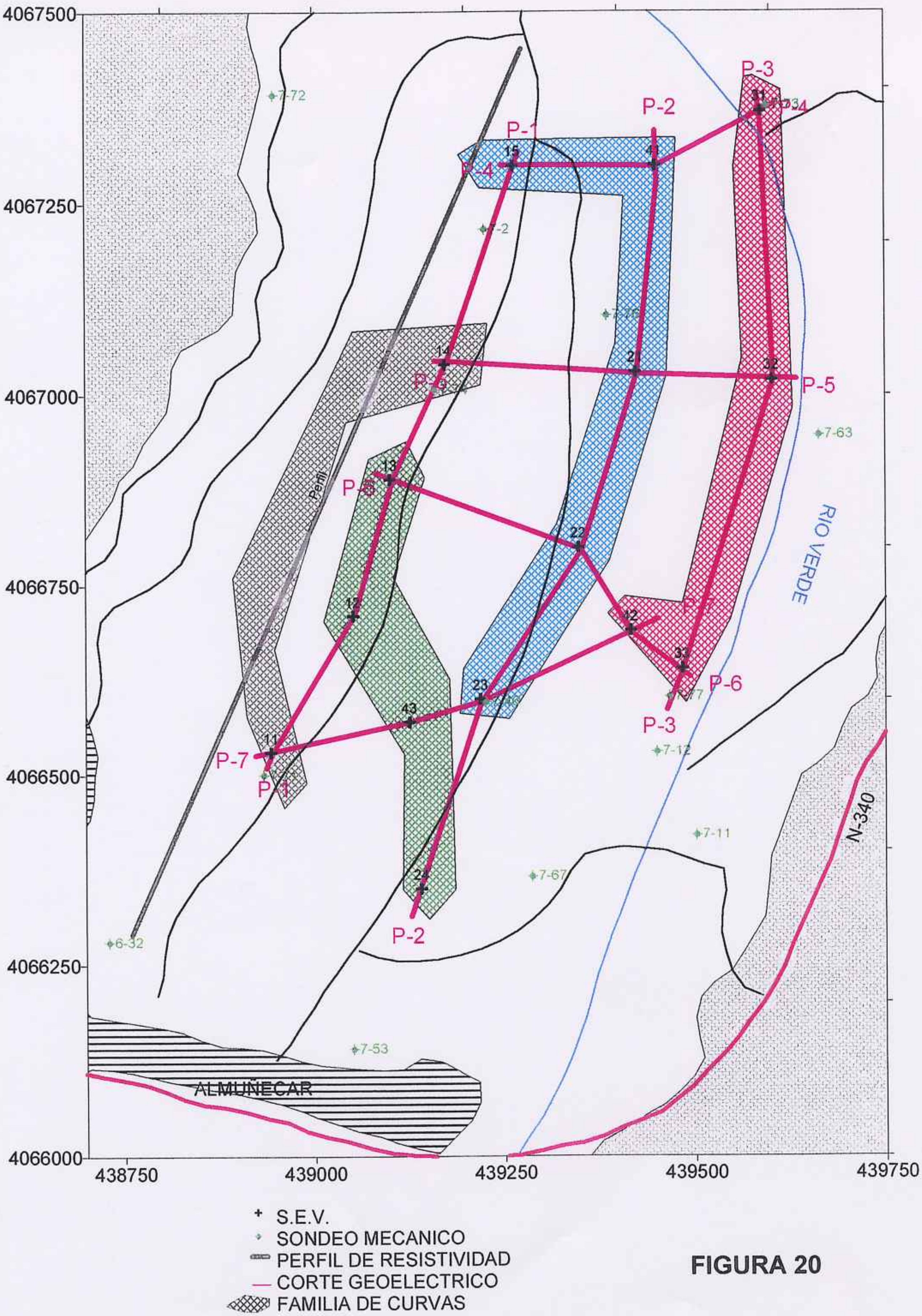


200 ——— Línea de igual contenido en cloruros (mg/l)

o Punto de control

– – – – Posible barrera a la circulación del agua

FIGURA 13. Mapa del contenido de isocloruros del acuifero de Almuñecar. (Noviembre 1982).



4067500
4067250
4067000
4066750
4066500
4066250
4066000
438750
439000
439250
439500
439750
P-1
P-2
P-3
P-4
P-5
P-6
P-7
15
41
31
14
21
32
13
22
12
42
33
23
43
11
24
7-72
7-2
7-63
7-12
7-11
7-67
6-32
7-53
Perfil
RIO VERDE
N-340
ALMUÑECAR
S.E.V.
SONDEO MECANICO
PERFIL DE RESISTIVIDAD
CORTE GEOELECTRICO
FAMILIA DE CURVAS

FIGURA 20

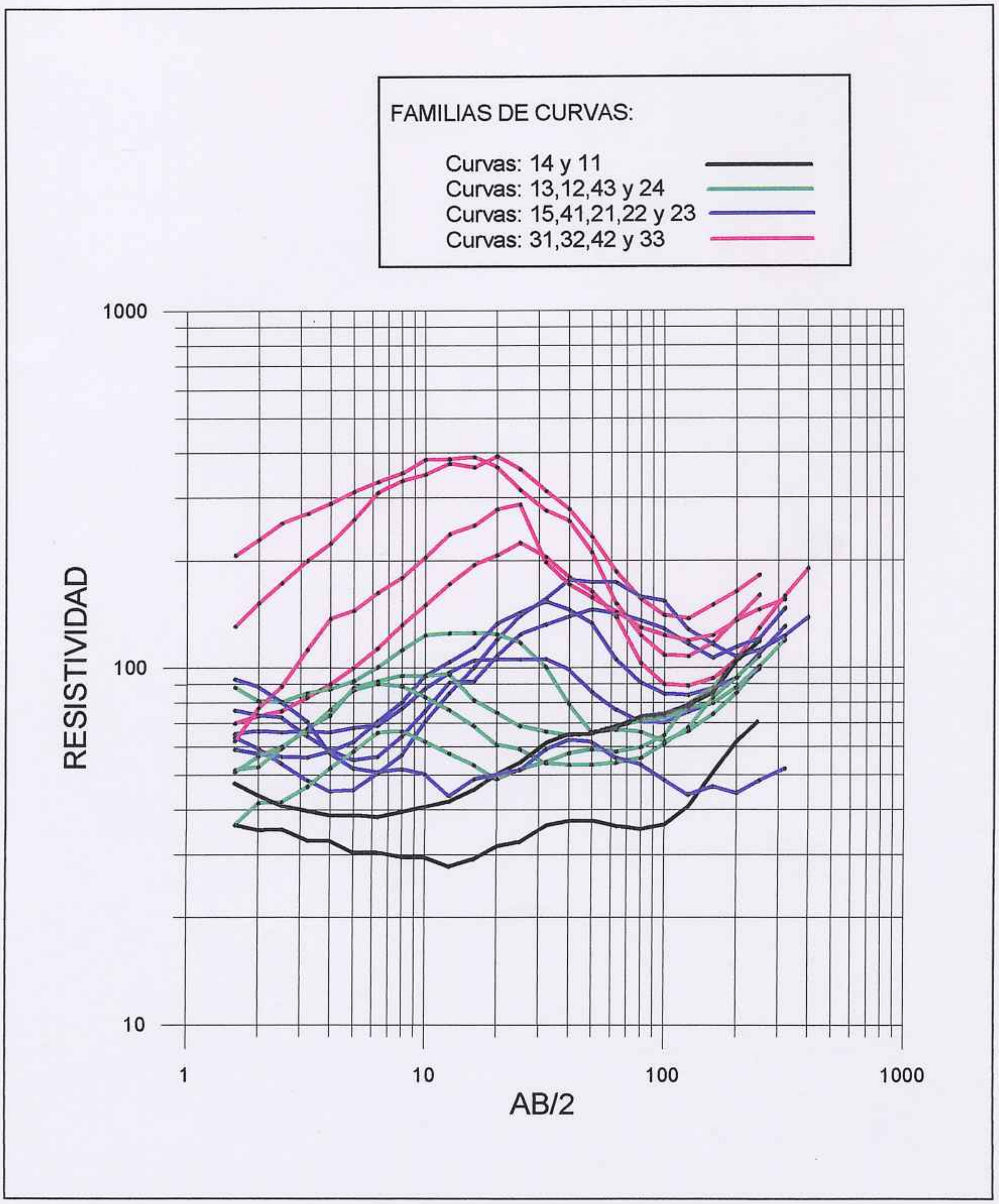
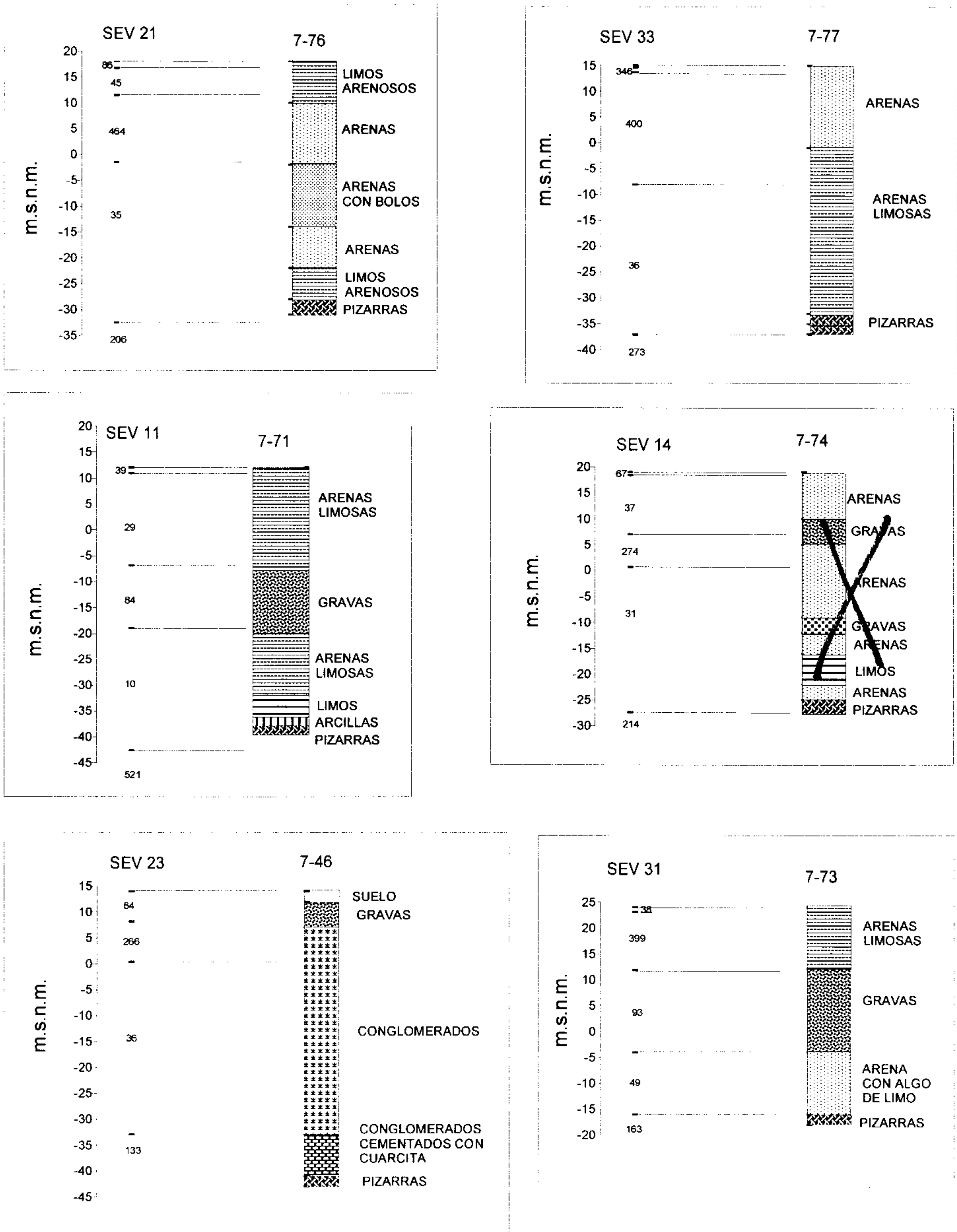
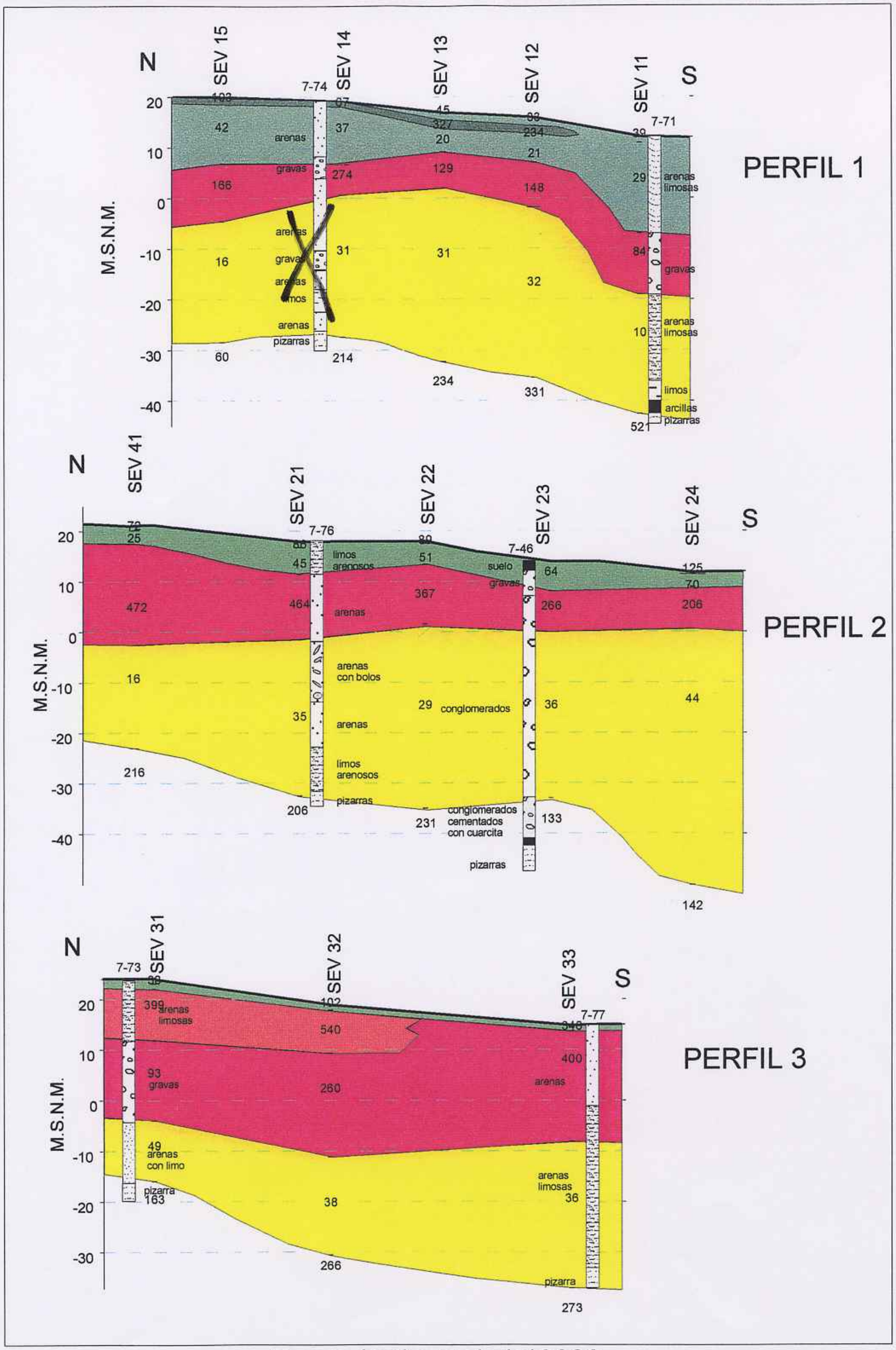

FAMILIAS DE CURVAS:
Curvas: 14 y 11
Curvas: 13,12,43 y 24
Curvas: 15,41,21,22 y 23
Curvas: 31,32,42 y 33
RESISTIVIDAD
1000
100
10
1
10
100
1000
AB/2

FIGURA 21

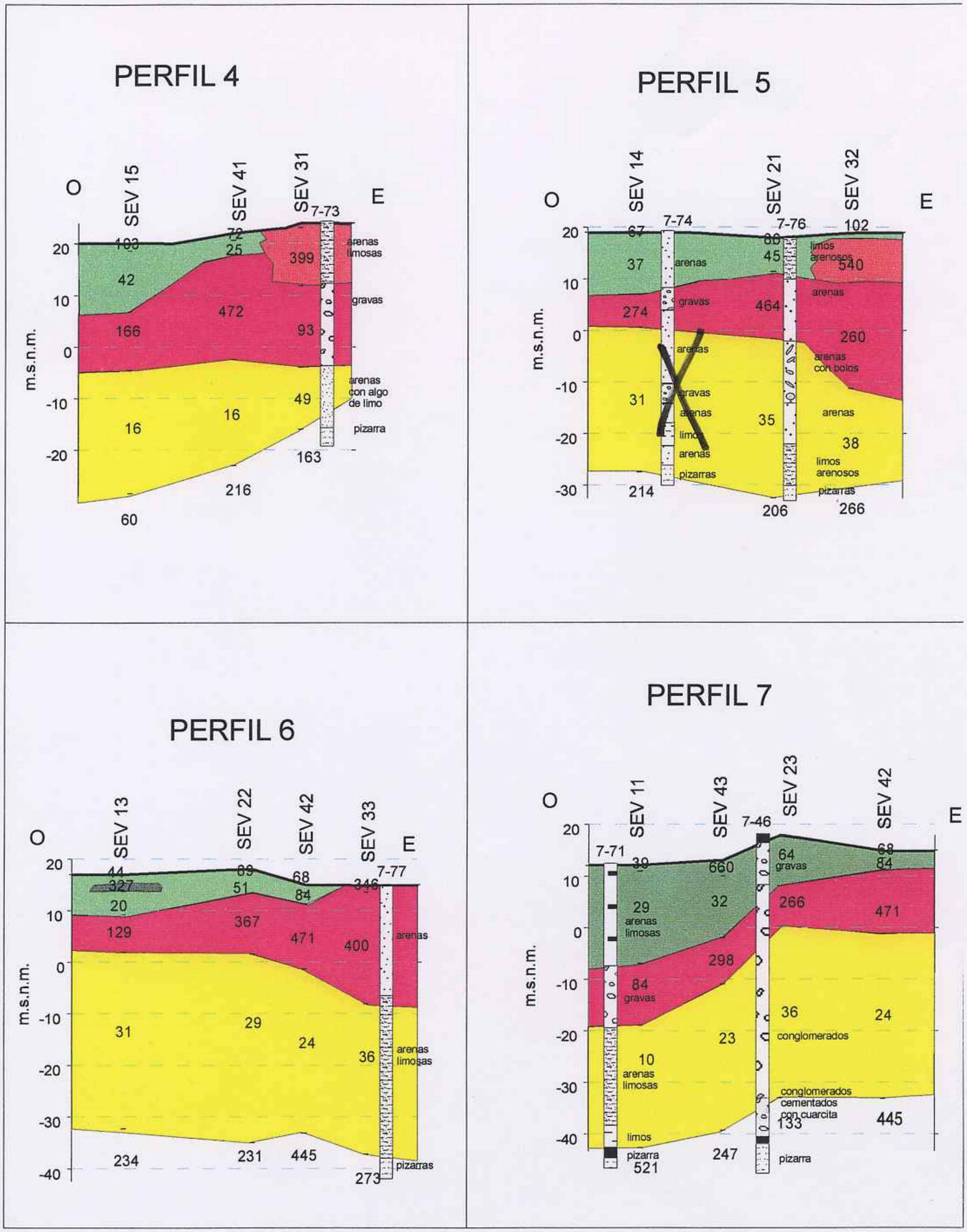


SONDEOS PARAMETRICOS **FIGURA 22**



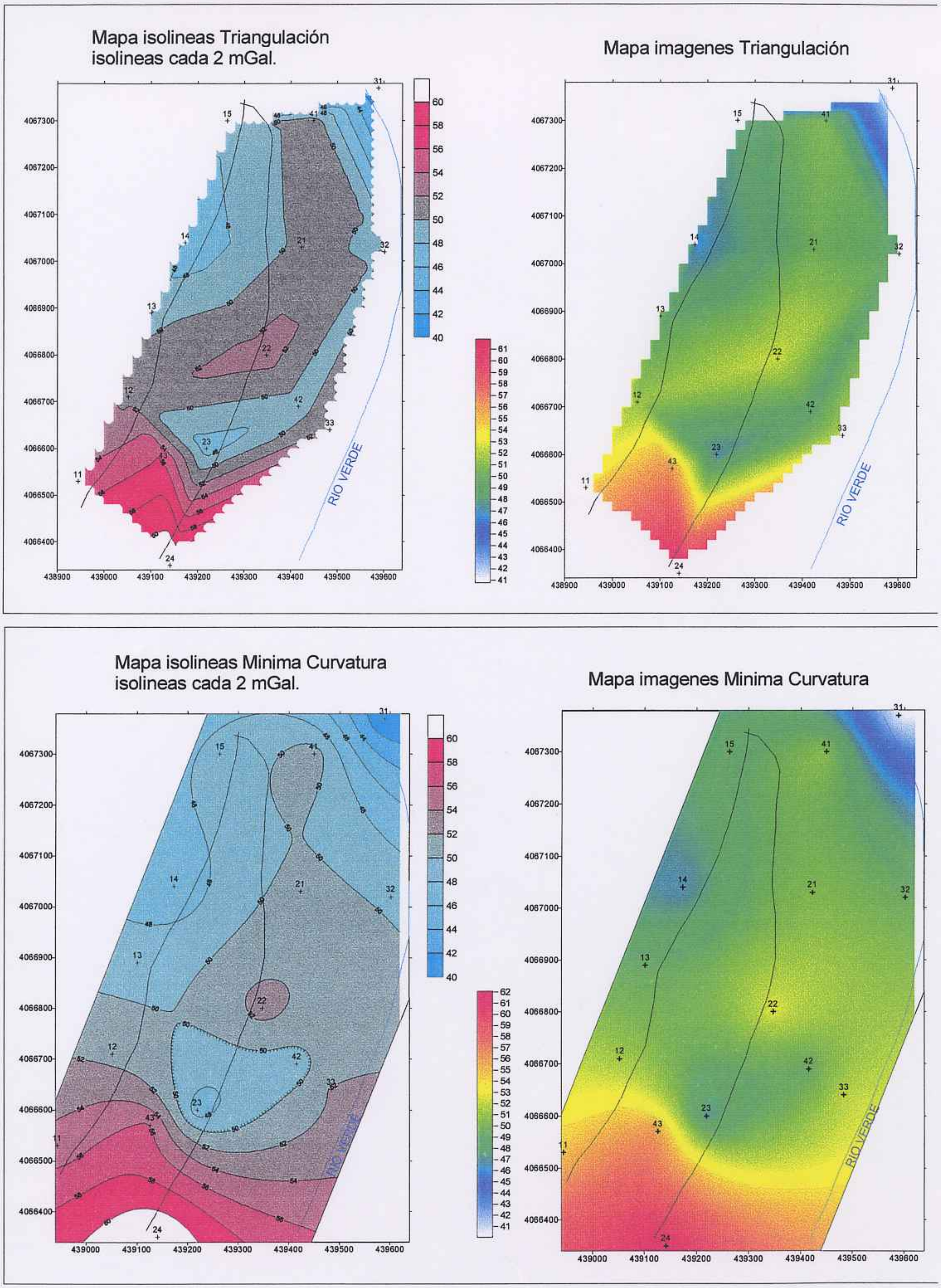
Escala horizontal :1:10000
Escala vertical: 1:1000

FIGURA 23



escala horizontal= 1/10000
escala vertical= 1/1000

FIGURA 24



Mapas de profundidad del sustrato a partir de la interpretación de los sondeos electricos verticales.

21
+ Posición y número de los sevs

FIGURA 25

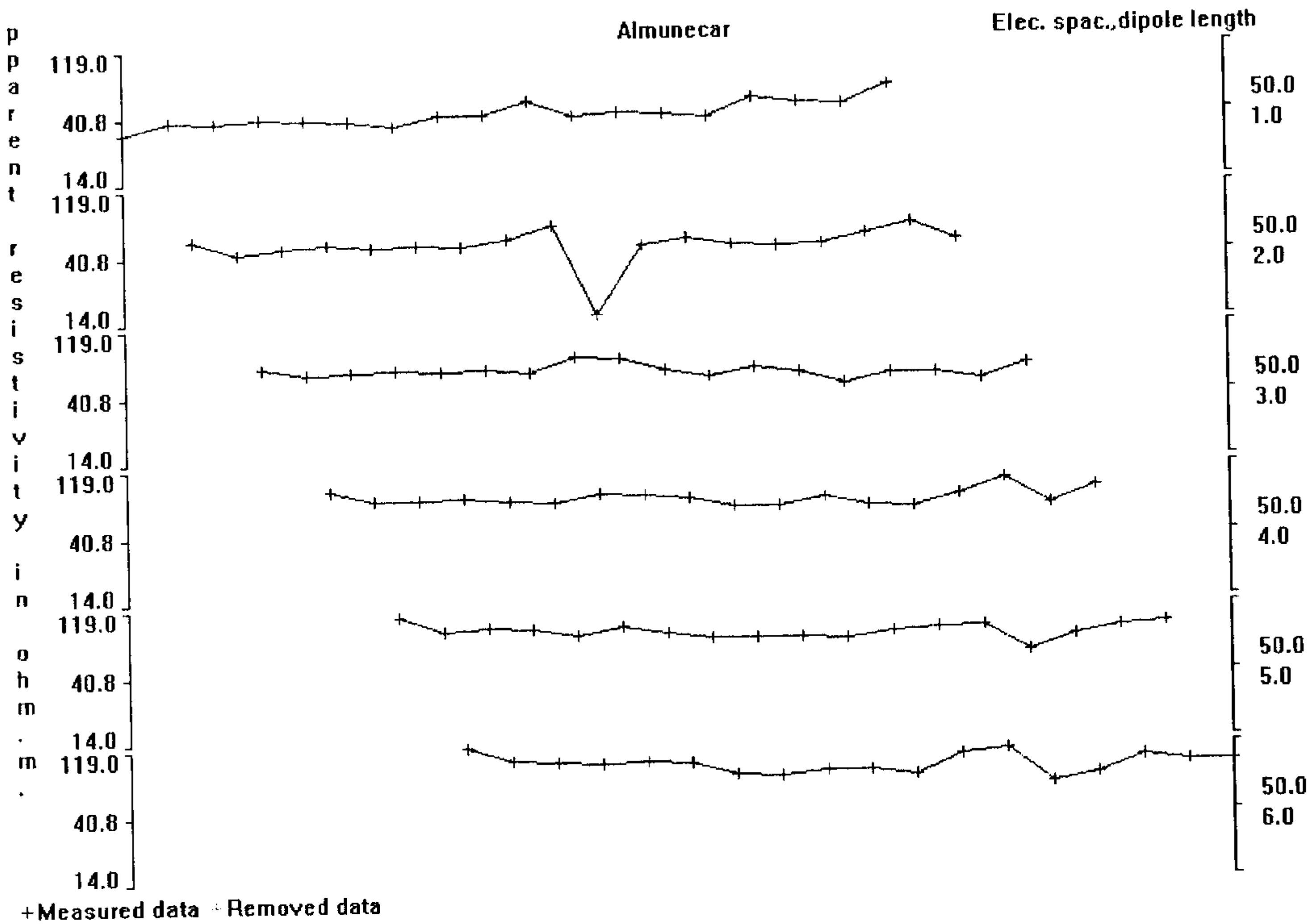

Almunecar
Elec. spac.,dipole length
pparent resistivity in ohm.m.
119.0
40.8
14.0
50.0
1.0
2.0
3.0
4.0
5.0
6.0
+Measured data
Removed data

FIGURA 26

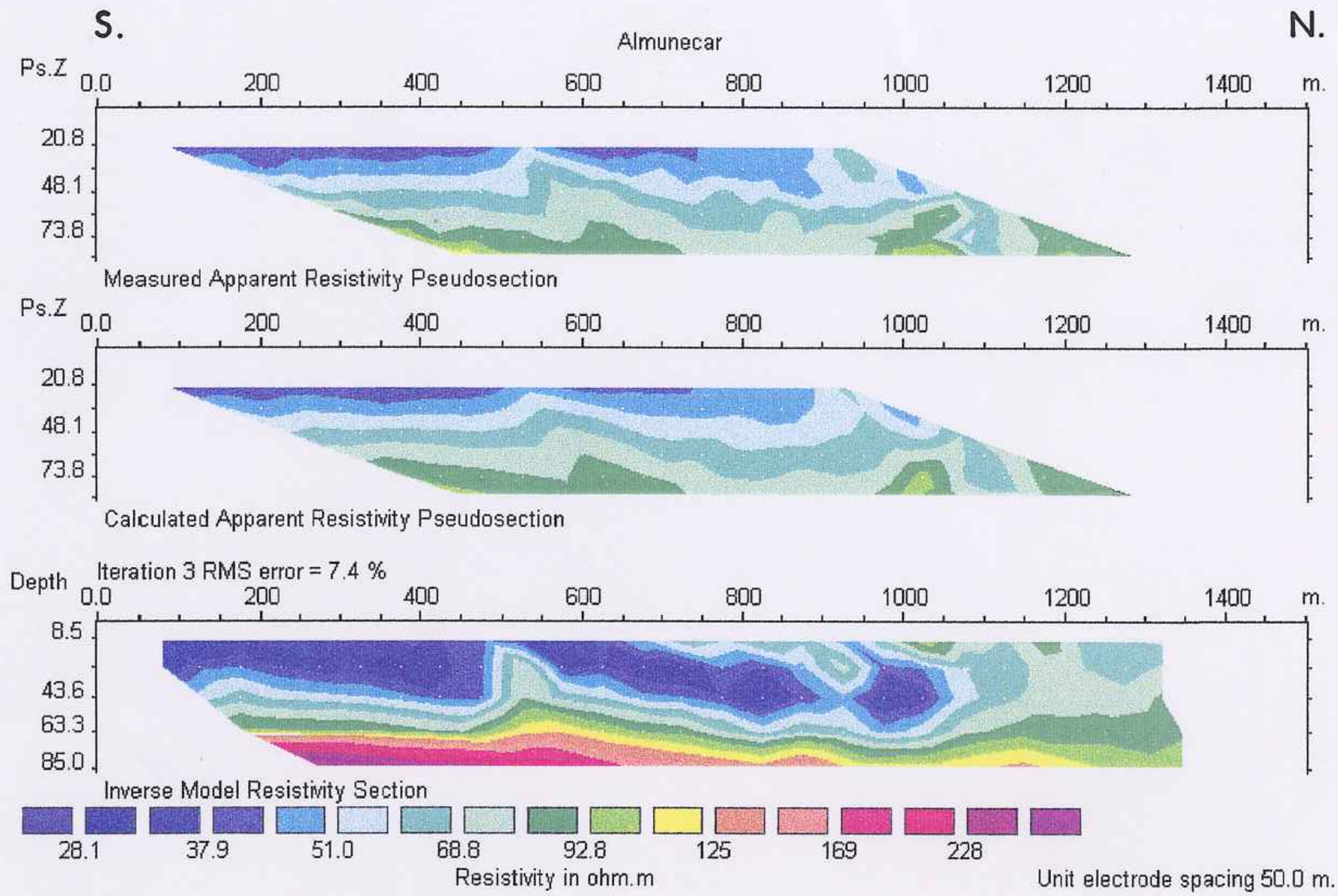
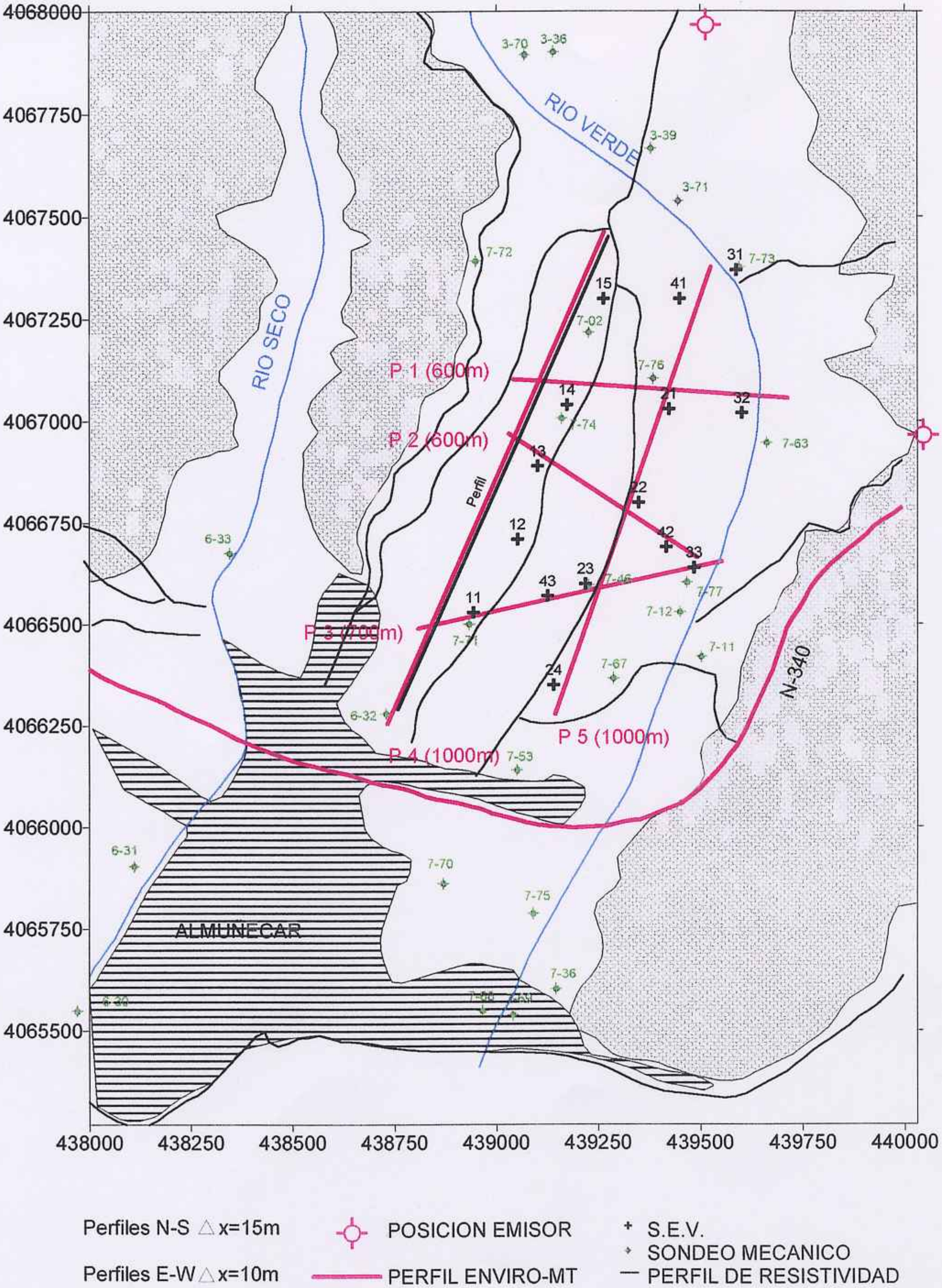

S.
N.
Almunecar
Ps.Z
0.0
200
400
600
800
1000
1200
1400
m.
20.8
48.1
73.8
Measured Apparent Resistivity Pseudosection
Ps.Z
0.0
200
400
600
800
1000
1200
1400
m.
20.8
48.1
73.8
Calculated Apparent Resistivity Pseudosection
Depth
Iteration 3 RMS error = 7.4 %
0.0
200
400
600
800
1000
1200
1400
m.
8.5
43.6
63.3
85.0
Inverse Model Resistivity Section
28.1
37.9
51.0
68.8
92.8
125
169
228
Resistivity in ohm.m
Unit electrode spacing 50.0 m.

FIGURA 27



4068000
4067750
4067500
4067250
4067000
4066750
4066500
4066250
4066000
4065750
4065500
438000
438250
438500
438750
439000
439250
439500
439750
440000
RIO SECO
RIO VERDE
N-340
ALMUNECAR
Perfil
P 1 (600m)
P 2 (600m)
P 3 (700m)
P 4 (1000m)
P 5 (1000m)
3-70
3-36
3-39
3-71
7-72
7-73
7-02
7-76
7-74
7-63
7-77
7-12
7-11
7-67
7-53
7-70
7-75
7-36
6-33
6-32
6-31
31
15
41
14
21
32
13
22
12
42
33
43
23
11
24
Perfiles N-S △ x=15m
Perfiles E-W △ x=10m
POSICION EMISOR
PERFIL ENVIRO-MT
S.E.V.
SONDEO MECANICO
PERFIL DE RESISTIVIDAD

FIGURA 29