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DEPARTMENT OF GEOPHYSICS
Section of Solid Earth Physics

JBA

Instituto Tecnológico GeoMinero de España

ENVIRO-MT TECHNOLOGY TRANSFER PROJECT
Contract Nº IN100480I

Work package 4: Task 4.3.2.: " Field testing of ENVIRO-MT at demonstration site 2"
Deliverable D45

REPORT ON THE INTERPRETATION OF ENVIRO-MT DATA FROM TEST SITE OF ALMUÑECAR (SPAIN), 1999.

Written by: J. Plata. ITGE. Spain
version: sept./99

PROYECTO ENVIRO-MT

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Instituto Tecnológico GeoMinero de España

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1. INTRODUCTION

In January 1999 a "PREDEMONSTRATION DATA PACKAGE FOR THE FIELD TEST SITE OF ALMUÑECAR (SPAIN)" was prepared (D41 of Work Package 4, task 4.1.1); a description of the hydrogeological and geophysical information of the area, as well as the objectives to be achieved can be found in that report, where a proposal for the planning of the ENVIRO-MT test survey is also included.

In the present report the results of this survey are going to be analyzed only from the geological point of view, by comparison of ENVIRO-MT data with the previous geological and geophysical information available. No attention will be paid here to the instrumentation itself, because the suggestions and recommendations to the technology providers have already been included in the Minutes of the several Project Meetings, and in other deliverable documents. Description and comments about the data processing involved are not either under the scope of this report.

After discussion with some of the partners, the final planning for the ENVIRO-MT test survey in Almuñecar (ANNEXO I) was to measure two longitudinal profiles along the valley, of 1000 m each with readings every 15 m, and three transversal profiles of 600 m each with readings every 10 m; a total of 414 readings (at a mean rate of 10 readings per hour) was then proposed, including a repeatability and productivity test, a horizontal resolution test, and a transmitter position dependence test. The situation of the proposed profiles was chosen in order to use the available information from the boreholes and VES as control points to fulfil the objective of determining the geometry of the aquifer (thickness, extension and nature of the different layers), as well as the morphology of the substratum.

2. FIELD WORK DESCRIPTION

Field data have been collected from 12 to 23 April 1999. Profiles 1, 5 and 7 of the proposed ones (see map in Fig. 1) were selected to start with. The different tasks were distributed among three crews: the surveyors were in charge of putting one wood stick marked with the station number at every point where a reading was going to be taken, and to provide its UTM coordinates; another crew was in charge of the antenna mounting, displacement and control, and the third one was in charge of the receiver.

Description of the profiles:

The details of the profiles measured are[1] (see map of Fig.1 and Fig. 2, where real field numbers for the wood sticks are used):

* **L1**, with 72 stations every 15 m, numbered from north to south, longitudinal to the valley; station L1-1 is at 25 m to the west of the junction of Camino de la Vega (C.V.) 1° and 2°, and the last station L1-72 is just on C.V. 1°. It was measured every two stations (every 30 m) for RMT+CSMT simultaneously, starting from the south, with transmitter in position Tx4 (at a distance of 410-480 m from the stations) for the first 18 readings at the south of the profile, and in position Tx5 (from 470 to 720 m) for the rest. The 36 ENVIRO-MT readings were taken in two days.

* **L5**, with 57 stations every 10 m, from east to west, transversal to the valley, with an offset of 10 m to the north from station 39; station L5-28 is on C.V. 2°, and station L5-38 on C.V. 1°; crossing of L1 and L5 is between stations L1-14 and L1-15, and stations L5-41 and L5-42. Readings taken:

. 56 readings with RMT every station (every 10 m), from east to west, in about 4 h.

. 28 readings for CSMT, every two stations (every 20 m), from east to west, with source in position Tx1 (at a distance of 160 m to 410 m from the stations), in 9 h.

. 11 readings for RMT+CSMT, every five stations (every 50 m), from west to east, with antenna in position Tx2 (from 450 m to 550 m), in about 6 h.

* **L77**, with 52 stations every 10 m (and 54 wood sticks), from east to west; it has an offset of 30 m to the North from station 17b to station 36, while station 17a and 36a are in the original lineation; station L77-5 is on C.V. 2°, and L77-31 on C.V. 1°; crossing of this profile with L1 is between stations L77-39 and L77-40, and L1-63 and L1-64. It has been measured for RMT+CSMT simultaneously every two stations (20 m), from east to west, with a total of 26 readings; source was at position Tx3 (440-520 m) for stations 1 to 31, and at position Tx4 (410-480 m) for the rest. Time spent was two days.

(**L7**, with 63 stations every 10 m was a first setting for profile 7, but due to the great deviation from the position planned, no geophysical measurement were taken, and profile L77 was made instead.)

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[1] In ANNEXO II, the original documentation supplied by JBA is included. Discrepancies between the location of the stations and boreholes given in this description and the situation shown in Fig. 1, Fig. 2, and JBA maps are due to errors in stations coordinates and nomenclature.

Agenda for the field work:

The development of the work was as follows (see Fig. 2):

. Tuesday 13 was dedicated to prepare the instrumentation, to make the first trial readings and preparing the stations on Line 5.

. On Wednesday 14 Line 5 was completely measured for RMT every 10 m and also some readings with CSMT with antenna in Tx5 were taken, without valid measurements; Line 7 was prepared.

. On Thursday 15, readings for CSMT with transmitter in Tx1 were done on Line 5 every 20 m, Line 77 was started by surveyors and Training Meeting took place in the afternoon, with the assistance of everybody.

. Friday 16: CSMT measurements on Line 5 with Tx1 were ended and new measurements with RMT+CSMT every 50 m were taken with Tx2. Survey of Line 77 was finished.

. On Saturday 17, Line 5 with Tx2 is finished. Synchronization and calibration of instruments. Survey of Line 1 is started.

. On Monday 19, Line 77 is started for RMT+CSMT every 20 m, with Tx3. Project Meeting without interruption of field work.

. Tuesday 20: Line 77 is finished with Tx4 and Line 1 is started for RMT+CSMT with Tx4.

. On Wednesday 21 Line 1 is finished with Tx5.

Evaluation of the ENVIRO-MT field work:

The following data were taken, and are available for system evaluation, processing and geological interpretation:

Line	interval	n° readings	length	direction	method	TX position
L1	30	36	1050	N-S	RMT+CSTMT	Tx4, Tx5
L5	10	56	550	E-W	RMT	
L51	20	28	540	E-W	CSTMT *	Tx1
L52	50	11	500	E-W	RMT+CSTMT	Tx2
L77	20	26	500	E-W	RMT+CSTMT	Tx3,Tx4

* these readings have not been taken into account because the antenna was too close to the stations.

A total of 73 readings of RMT+CSMT were taken, with a mean production rate of 3 readings per hour (no productivity test was done); another 56 readings for only RMT, and 28 readings for only CSMT were also taken.

To evaluate repeatability for RMT, only some of the readings taken every 10 m on L5 and repeated every 50 m in profile L52 could be used, as well as stations at the crossing points of profiles. No repetition has been made for CSMT with the transmitter at the same position.

No test for the influence of the transmitter position on CSMT measurements has been made either; some of the readings taken in profile L51 every 20 m with Tx1 and repeated every 50 m in L52 with Tx2, could be used for this purpose, as well as the crossing stations of the profiles L1 and L5 (measured with Tx1, Tx2 and Tx5), because L1 and L77 are both read with Tx4 at their crossing portions.

Nevertheless, as the ENVIRO-MT readings are only identified by a sequential reading number, no guarantee exists for the exact identification of their field position (correspondence between reading number and field station number). To avoid more confusion, no comparison will then be made with these readings to deduce repeatability, influence on antenna position, etc.

The main problems found during the field work were due to the noise produced by cultural interferences (mainly power lines), what demanded the repetition of some readings. The dense "chirimoya" plantation make it difficult the access to the stations, though it did not really slow down production, except in a few cases due to the interruption of radio communication with the transmitter; in fact ENVIRO-MT system has proved to be a very suitable system to be used in difficult terrain conditions, where other methods with longer electrodes arrays or bigger antennas are much more difficult to use. Some stop time was required for the need of doing some modifications of the command software (to allow negative increment for the numbering system, and to take CSMT readings after RMT readings without interruption of the sequence).

Some pictures of the field work are shown in Fig. 3 and Fig. 4:

. antenna setting in position Tx4
. view of the area from Tx4
. antenna setting in position Tx1
. receiver mounted on special litter
. displacing the measuring point through the profile

3. DATA PROCESSING

A description of the processing system followed at Uppsala University is given in ENVIRO-MT 6-monthly report (period 1 January- 30 june 1999). The result for the processed field data of profiles L1, L5, L52 and L77 have been received by ITGE. For each line there are two set of values: for the XY and YX directions. Each set has been processed by two methods: standard and TSVD (Truncated Singular Value Decomposition), to get resistivity-frequency and phase-frequency sections, for both RMT and CSTMT (when available). Inversion for Resistivity-depth values have been curried out just for the TSVD data using only RMT, CSTMT and both sources.

So the available sections are (all the Figures are in ANNEXO III):

L1 (readings 1 to 35-36) and L77 (readings 1 to 25-26):

Fig. 1-1 and 7-1	RMT standard f-rho XY RMT TSVD f-rho XY RMT standard f-phase XY RMT TSVD f-phase XY
Fig. 1-2 and 7-2	RMT standard f-rho YX RMT TSVD f-rho YX RMT standard f-phase YX RMT TSVD f-phase YX
Fig. 1-3 and 7-3	CSMT standard f-rho XY CSMT TSVD f-rho XY CSMT standard f-phase XY CSMT TSVD f-phase XY
Fig. 1-4 and 7-4	CSMT standard f-rho YX CSMT TSVD f-rho YX CSMT standard f-phase YX CSMT TSVD f-phase YX
Fig. 1-5 and 7-5	RMT TSVD rho-depth XY RMT TSVD rho-depth YX
Fig. 1-6 and 7-6	CSMT TSVD rho-depth XY CSMT TSVD rho-depth YX
Fig. 1-7 and 7-7	RMT+CSMT TSVD rho-depth XY RMT+CSMT TSVD rho-depth YX

L5 (readings 1 to 55-56):

Fig. 5-1	RMT standard f-rho XY RMT TSVD f-rho XY RMT standard f-phase XY RMT TSVD f-phase XY

Fig. 5-2	RMT standard f-rho YX	RMT TSVD f-rho YX
	RMT standard f-phase YX	RMT TSVD f-phase YX
Fig. 5-3	RMT TSVD rho-depth XY	
	RMT TSVD rho-depth YX	

L52 (readings 1 to 10-11):

Fig. 52-1	RMT standard f-rho XY	RMT TSVD f-rho XY
	RMT standard f-phase XY	RMT TSVD f-phase XY
Fig. 52-2	RMT standard f-rho YX	RMT TSVD f-rho YX
	RMT standard f-phase YX	RMT TSVD f-phase YX
Fig. 52-3	CSMT standard f-rho XY	CSMT TSVD f-rho XY
	CSMT standard f-phase XY	CSMT TSVD f-phase XY
Fig. 52-4	CSMT standard f-rho YX	CSMT TSVD f-rho YX
	CSMT standard f-phase YX	CSMT TSVD f-phase YX
Fig. 52-5	RMT TSVD rho-depth XY	
	RMT TSVD rho-depth YX	
Fig. 52-6	CSMT TSVD rho-depth XY	
	CSMT TSVD rho-depth YX	

A qualitative interpretation made by Uppsala University for some of these sections may also be found in the ENVIRO-MT last 6-monthly report, where an evaluation of the different processing systems is also included. The geological interpretation will be done on the rho-depth sections.

4. CONTROL POINTS FOR THE RESISTIVITY SECTIONS

The geological information provided by some of the existing boreholes, and the resistivities found in the VES survey made by ITGE in 1998 can be used as control points for the resistivity and depth values calculated from ENVIRO-MT measurements. No priority is given to either of the geophysical methods, but this comparison is the only way to verify that ENVIRO-MT measurements are providing a geological image of the underground and to draw conclusions of the advantage and disadvantage of its use.

To make this comparison it is necessary to identify the positioning of the geophysical measurements in regard to the control points. Due to the coordinates and numbering problems, we have put all the VES and borehole information over the ENVIRO-MT sections at our best criterium; a precision better than 50 m can not be ensured; this error is not important for the correlation with VES interpretation, because this kind of data are representative of a much greater volume of the underground (AB/2 varies from 250 m to 350 m) than the ENVIRO-MT data, and are taken at a distance of about 200-250 m apart, showing the general geological trend.

The control points are (see Fig. 1 and Fig. 2):

* **Line 1**: may be compared with VES "Perfil 1" and the resistivity and IP pseudosection.

  - borehole 7-71 is at 22 m of station L1-63 (may correspond to reading 32-30?)
  - borehole 7-74 is at 50 m of station L1-22 (may correspond to reading 11-12?)

    - all VES are closer than 25 m from the section;
      . VES 11 is in front of station 61 (reading 30-31?)
      . VES 12 is in front of station 46 (reading 23-24?)
      . VES 13 is in front of station 34 (reading 17-18?)
      . VES 14 is in front of station 23 (reading 11-12?)
      . VES 15 is in front of station 5 (reading 3?)

    - crossing with L5 is between stations 14-15 (reading 7?)
    - crossing with L77 is very ambiguous, due to the offset of L77, and may be considered as a segment between stations 60 and 64 (readings 30-32?)

* **Line 5**: is situated between VES "Perfil 4" and VES "Perfil 5".

  - borehole 7-76, is 10 m to the south of station 27.

- VES 32 is at 35 m to the south from station 5
- VES 21 is at 65 m to the south from station 21
- VES 14 is at 130 m to the south from station 46
- VES 15 is at 130 m to the north from station 46

- crossing with L1 is between stations 41-42

* **Line 77**: can be compared with the western portion of VES "Perfil 7".

- borehole 7-46 is coincident with station 5 (reading 3?)
- borehole 7-71 is at 20 m from station 36a (reading 20?)

- VES 23 is by station 5 (borehole 7-46)
- VES 43 is at less than 30 m from station 14 (reading 7?)
- VES 11 is by borehole 7-71

- crossing with L1 is very ambiguous, due to the offset of L77, and may be considered as a segment between stations 36 and 40 (readings 18-22?)

The different system used in the graphical representation of the results must also be taken into account. Resistivity contacts in ENVIRO-MT sections are diffused in a wide range of depths, while in VES sections and borehole geological logs they are sharp boundaries. In ENVIRO-MT sections the topographic relief is not considered, and a different horizontal scale for each sections has been used. The extrapolation of the resistivity information up to 100 m in the ENVIRO sections may be also a source of confusion.

5. INTERPRETATION OF SECTION 1

In the document "PREDEMONSTRATION DATA PACKAGE FOR THE FIELD TEST SITE OF ALMUÑECAR (SPAIN)" a description of the geology and geoelectrical data of the area may be found. The situation may be briefly described as follows (Fig. 5): over a resistive Palaeozoic substratum (which may belong to different tectonic units), the alluvial deposits of quaternary materials form a sequence of layers of silt, clay, coarse sands and gravels, medium sands and silty fine sands. The thickness of the alluvial increases to the South, and though it may present some variations and intercalations, it is supposed to be more homogeneous in a north-south direction than in the transversal direction, due to the existence of paleochannels (see Fig. 5), which have the highest hydraulic permeability. The correlation between lithology and VES resistivity values shows a great variation, due to the influence of the water content and also to the variations in the clay and silt content; changes in conductivity are important because they may be associated with variations in hydraulic permeability. The general situation is nevertheless well described in the geoelectrical sections drawn with the interpretation of the VES survey, which are partially reproduced in Fig. 6. In some boreholes (mainly in S-7-46) the description of the lithology is rather poor.

The ENVIRO-MT section of Line 1 can be readily compared with VES section of Perfil 1, where the general geoelectrical situation from the surface to the bottom is (each geoelectrical layer is going to be denominated by a letter to facilitate the description):

(a) - A first resistive layer (100-600 ohm-m) of about 2 m thick is detected from the North until VES 12, and is sometimes overlaid for a more conductive layer. It is present all over the area, except in the South, and may be due to dry soil.

(b) - A conductive layer (20-80 ohm-m, of medium sands with silt) with 10 m of mean thickness, reaching 18 m in VES 11.

(c) - A resistive layer (100-470 ohm-m, of coarse sands and gravel, probably dry at the time of the VES survey) about 10 m thick, closer to the surface in the middle of the section, and may be interrupted between VES 12 and 11.(This layer increases its thickness and resistivity to the East, nearer to the actual river bed)

(d) - A conductive layer of 20 m to 30 m of thickness (10-40 ohm-m, of medium sands with silt, and some intercalations of gravel), with its top also deeper in the South. It may constitute the main aquifer, and its top should be the water table.

(e) - A resistive basement (200-500 ohm-m, of shales), dipping to the south. In some VES a lower resistivity is found for this basement.

A quantitative comparison of resistivities and depth values between RMT and CSMT (Fig. 1-5 and 1-6 on Annexo III) sections and VES sections has not been curried out, because first tries are not very encouraging. From a qualitative point of view:

* Section Line 1 RMT (15-200 kHz) for XY and YX (Fig. 1-5) do not show any information below the second conductive layer (d), with a penetration no greater than 30-35 m. The sequence of resistivities is in coincidence with the VES section, but with higher values for the XY direction.

* Section Line 1 CSMT (1-15 kHz) for XY and YX (Fig. 1-6) do penetrate the second conductive layer (d), giving information about the basement (e) depth, but it sees the detrital sequence mainly as a conductive layer with a resistive layer at the surface. This section is quite similar to the dipole-dipole section presented in the Predemonstration Report.

Shallow resolution is better with RMT measurements, as expected, and in situations like this one, where depth to the basement is also required, both MT sources must be used to achieve resolution and penetration.

* A more detailed analysis can be done with section Line 1 for RMT+CSTMT XY and YX (Fig. 7):

. In the south, for borehole S7-71 and VES 11 (with good correspondence between resistivity and lythological boundaries), correlation with ENVIRO-MT resistivity values is not good for the XY direction, being better for the YX direction.

. At the North, correspondence between borehole S7-74 (new revised lythological description) and resistivities of VES 14 shows that the geoelectrical response of the group of layers below the 274 ohm m of gravel is equivalent to a single geoelectrical conductive layer (31 ohm m), of higher resistivity than in VES 11 (10 ohm m) because of the more abundant content of sand. The correlation of ENVIRO-MT resistivity values with VES values is good for both XY and YX directions (better for YX).

For the rest of the section, which is only covered by VES information, and from bottom to surface:

. Depth to the basement (e) correlates better with YX section; the higher conductivity found in VES 15 (60 ohm m) is in nice coincidence with ENVIRO results, and can be interpreted as a variation in the nature of the substratum, more rich in graphite at the North, and is perfectly compatible with the geological information (see geological map Fig. 3 in Predemonstration Report); this conclusion can be better supported by ENVIRO-MT results, because the change in resistivity has been found in at least 5-6 consecutive measurements. At the other points of the section (readings 15 and 33), a more conductive layer appears in depth; it seems not to be corroborated by the frequency section (Fig. 1-3 and 1-4 of Annexo III), and is perhaps due to one strange artefact in inversion.

. The conductive layer (d) has a good match for its top in XY section, but, as previously stated, its bottom is in better coincidence with section YX; if this layer represents the main aquifer, the more horizontal boundary defined by ENVIRO in the YX direction is more confident than the

VES limit. Both, VES and ENVIRO, find a more resistive behaviour of this layer at the central portion of the section, and more conductive at both ends, though this detail is more clear in YX direction. This resistivity variations may be due to the clay content or to the water content; no chargeability anomaly appears in the IP profile (see position in Fig. 1), but these measurements are taken 100 m to the West, so new data should be taken to find the correct interpretation. Boundaries for interpretation of VES 15 should be revised; a conductive lens at 20-30 m depth in ENVIRO measurements 1-3, may be linked with an IP anomaly found in the IP profile, which can then be produced by a higher content in clay.

. Boundaries for the next resistive layer (c) (gravel and coarse sand), are in good agreement with XY section, though its top is also good for YX section. The 84 ohm m of VES 11 was correlated in the VES section with this layer (see Fig. 6, Perfil 1); it is rather clear now that in fact this portion of the profile represents a different lens of gravels, which are under the water table and presents a lower resistivity (this circumstance is more clearly appreciable when using the topographic relief of the section, that lowers the level of this layer).

. Conductive layer (b) fits very well with values of YX section.

. For the shallowest layer (a), in spite of its small thickness of less than 2 m, both section present a good match with the VES and geological information, though it is again better for the YX section.

A conclusion can be that the ENVIRO-MT results in this section reflects very well the available geological information, in a continuous fashion, what allows a better understanding and correlation of the geographical distribution of the different layers of the aquifer; YX sections fits better with the geoelectrical information than XY sections, except for the thickness and continuity of the second conductive layer (d). The values for the apparent resistivity are of the same order of magnitude for both methods.

6. INTERPRETATION OF SECTION 77

The ENVIRO-MT section of Line 77 can be readily compared with a portion of VES section Perfil 7 (Fig. 1), between boreholes 7-46 in the East and 7-71 in the West; the general geoelectrical situation is (Fig. 6):

(a) - The shallow resistive layer of Perfil 1 is more conductive here, and only in the middle of the section a more resistive area one metre thick may be found (VES 43, 660 ohm m)

(b) - This conductive layer has about 10 m in the East, increasing its thickness up to 20 m to the West.

(c) - This resistive layer is 10 m thick, dipping to the West, where it is more conductive.

(d) - This conductive layer has 25 m to 30 m of thickness, and is also dipping to the West, where the conductivity is also higher.

(e) - The resistive basement, dips to the west.

* Section Line 77 RMT (15-200 kHz) for XY and YX (Fig. 7-5 on Annexo III) do not show any information below the second conductive layer (d), with a penetration no greater than 30-35 m in the western part, that reaches up to 60 m to the East. The sequence of resistivities is more or less coincident with the VES section, but the conductive layer seems to dip to the East, even if the relief is taken into account. There is a great difference between the topography of top of the last conductive layer in section XY (with a high below readings 7-8) and YX (with a high below readings 3-4), also reflected in the CSMT section.

* Section Line 77 CSMT (1-15 kHz) for XY and YX (Fig. 7-6 of Annexo III) do penetrate the second conductive layer, giving information about the basement depth. As in section Line 1, it sees the detrital terrain mainly as a conductive layer with a resistive layer at the surface in the East and more conductive to the West, which is in coincidence with the VES section. Topography of basement dips to the East, and presents great differences between both directions. XY section has a more confident geological looking that YX section, where the topography and resistivity of the basement presents many irregularities.

* A more detailed comparison will be done with section Line 77 for RMT+CSTMT XY and YX (Fig. 8). It is worth to mention, at least as a curiosity, the great similitude between Line 1 and Line 77.

. To the West, correlation of borehole 7-71 and resistivities of VES 11 with ENVIRO-MT resistivities is the same than in Line 1, better for the YX direction.

. Crossing of section 1 and 77 presents a good match for both XY and YX directions.

. To the East, geological column for borehole S7-46 is not very reliable, except for the depth to the basement, and has no correspondence with the resistivity values of VES 23; ENVIRO-MT resistivity values match better with VES values for YX direction.

. In between of the two previous control points, VES 43 has a fair correlation with the ENVIRO-MT values for both XY and YX directions.

. There is a great variation in the resistivity of the basement (e), and even a more conductive area appears in depth between readings 15-20, with a doubtful geological meaning. Its depth fits well at the control points; the elevation of more than 15 m in the central portion of the profile corresponds to the offset of 30 m to the North of the stations in this line, and is only present in XY direction. The lower resistivity in the Eastern end is also found by VES 23 (133 ohm m), and can be interpreted as being the same contact (or fault ?) between different units of the basement.

. The boundaries of the conductive layer (d) are rather different in both sections, but in this case there is not enough control points to select the best one.

. In this line it appears again that resistive layer (c) can not be correlated with the 84 ohm m layer in the Western part, as was made in the VES section.

In conclusion, the general trend or sequence of electrical behaviour of the layers is in correspondence with the known situation, though the detailed values do not match in this section as well as in Line 1. The difference between XY and YX sections is here more important than in Line 1, and could be due to the more heterogenous geological situation expected to occur in the eastward - westward direction. ENVIRO-MT measurements allows also in this Line to modify some of the correlations made with VES sections, providing a better geological image.

7. INTERPRETATION OF SECTION 5

The geoelectrical situation in this profile can be interpolated from VES section of Perfil 4 and Perfil 5 (Fig. 1 and Fig. 6), and presents some differences with the one described for Section Line 1 and 77. From surface to bottom:

(a) - The first resistive layer of about 2 m thick is detected all over this area.

(b) - Conductive layer, which thickness increases to the West from 5 m to 10 m, and is not detected in the east end, by the river bed, where a more resistive layer (c') is present.

(c) - Resistive layer, nearly outcropping in the east part, where it presents a higher resistivity (c') and has a thickness of 25-30 m, getting thinner to the west, where it has 5-10 m.

(d) - Conductive layer of 10 m to 30 m, increasing also its thickness to the West.

(e) - Resistive basement

Only RMT values have been inverted for the complete section, with readings every 10 m (Fig. 9), giving information just to the top of the second conductive layer (d):

. To the West end of the section the geoelectrical situation should be something in between VES 15 (130 m to the North) and VES 14 (130 m to the South); the sequence for the resistivity of the ENVIRO-MT layers coincides with the VES sequence, but there is a great discrepancy in the depth values: the conductive layer (d) appears more than 10 m deeper than in VES sections, because the resistive layer (c) appears to be thicker in ENVIRO-MT. Remember that VES 14 fits well with ENVIRO-MT data in Line 1 for RMT+CSTMT inversion.

. The situation at VES 21, in the middle of the section, fits well with YX section, and very bad with XY, though the geological information from borehole 7-76 can be well correlated with VES results.

. At VES 32, the closest one to the ENVIRO-MT section, a good correlation with both XY and YX values can be found, with a high resistive layer outcropping to the East.

. Correlation of values for the crossing points with Line 1 for only RMT is good, mainly for XY direction.

In conclusion, the general trend of the resistivities distribution (a resistive outcropping layer which gets thinner to the West, where there is a more conductive layer closer to the surface) is in agreement with the known values, but the the coincidence of punctual data is very bad (this has also been noticed with the RMT or CSTMT section of the other lines, but in this case it is still worse). Layers in Line 5 present a great discontinuity, and the variations in depth to the top of the conductive layer (d) can not be accepted from a geological point of view; this situation could be a consequence of using 1D inversion with data with such a continuous coverage (10 m). The fact that geological structures can be more heterogeneous in a east-west trend do not justify this great variation and discontinuity.

This line has also been measured for RMT and CSTMT every 50 m, and the result of the inversion is in Line 52 (Fig. 52-5 and 52-6 of Annexo III). The exact comparison of the RMT values of Line 5 with Line 52 is not possible, because we can not identify with confidence the correspondence between readings every 10 m and every 50 m. On the same Fig. 9, we have put the depth to the top of layer (d) in Line 52 for RMT (Fig. 52-5); even taking in mind the sampling theorem, there are important differences, mainly in the western portion of the profile. The situation in Line 52 for RMT is more compatible with a sedimentary geological sequence, though there are important differences between XY and YX directions.

The CSTMT sections for Line 52 (Fig. 52-6) present an extraordinary different situation for XY and YX directions (it is like if the order of the readings were inverted), and has no geological meaning.

8.ABSTRACT AND CONCLUSIONS

Field data have been collected from 12 to 23 April 1999, along profiles 1, 5 and 7. A total of 414 readings (at a mean rate of 10 readings per hour) was proposed for this survey; in fact 73 readings of RMT+CSMT were taken, with a mean production rate of 3 readings per hour. No productivity test was done, but an industrial production rate could be something better than this one. Another 56 readings for only RMT, and 28 readings for only CSMT were also taken.

No mayor problems have been found for the field work, in spite of the great difficulties of the terrain; ENVIRO-MT system has proved to be a much faster and terrain adaptable system than traditional resistivity methods.

ENVIRO-MT readings are only identified by a reading sequence number, and it is not sure to what field station number they corresponds. Due to the discrepancies between the UTM coordinates given by the topographical crew and the coordinates formerly available for the boreholes and VES, the situation of the ENVIRO-MT results respective to the control points, as well as the identification of the crossing points of the different profiles, is not possible to be known with a precision better than 50 m.

No repeatability, horizontal resolution, and transmitter position dependence tests have been done; for this reason, only the general geological interpretation of the data can be analyzed in this Report. For this purpose inverted resistivity-depth sections for RMT+CSTMT have been considered.

Shallow resolution is better with RMT measurements, as expected, but penetration is very limited, and in situations like this one, where depth to the basement is also required, both RMT and CSMT sources must be used to achieve resolution and penetration. The interpretation of the resistivity-depth sections provided for each of the sources individually are not very suitable for geological interpretation, showing a significant difference for this purpose with the joint RMT+CSTMT sections.

For Line 1 (readings every 30 m), ENVIRO-MT results reflect very well the available geological information, in a continuous fashion, with a good resolution, both in depth and in lateral extension; this allows a better correlation of the different layers and a better understanding of the geographical distribution of the aquifer; YX sections give a better geological information than XY sections, except for the thickness and continuity of the second conductive (10-40 ohm-m) layer.

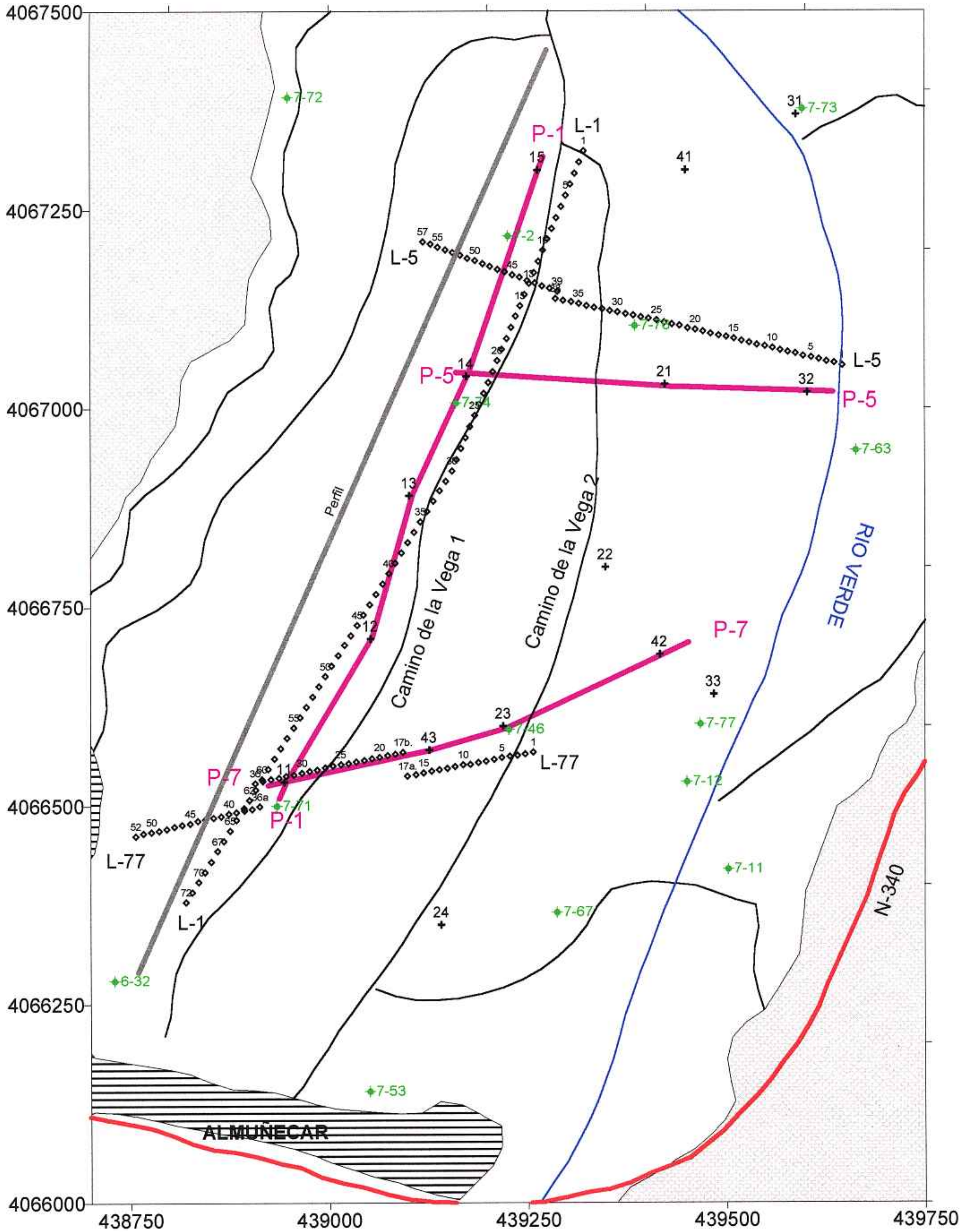
In Line 77 (readings every 20 m), though correlation of ENVIRO-MT values with VES and borehole values is not as good as in Line 1, the general trend or sequence of electrical behaviour of the layers is in correspondence with the known situation, allowing a better correlation. The difference between XY and YX direction is more important in this Line, showing a the great variation in the resistivity of the layers and depth to the basement, what could be due to the more heterogenous geological situation expected to occur in the eastward - westward direction, and, if real, would be a clear advantage of ENVIRO-MT method for this kind of structures. Crossing of Lines 1 and 77 presents a good match for YX direction, what could be taken as a proof of a nice repeatability.

In Line 5 (readings every 10 m), no correlation can be found of ENVIRO-MT resistivity-depth values with the known ones, except in the Eastern end. The layers present a great discontinuity and the relief of the top of basement appears to be too rough, with no geological meaning, and can be considered a consequence of the 1D inversion with such a continuous coverage of ENVIRO-MT measurements.

Our feeling is that more field experiments are needed to a fine tuning of the field data acquisition procedure; a confident criterium to be used by the user to identify in the field the quality of the data must be clearly established, so that bad data could be suppress from the section. A 2D inversion is needed to fully take advantage of the continuous coverage. Also, as tensor data are being collected, all the possibilities to use this information in the geological interpretation should be implemented.

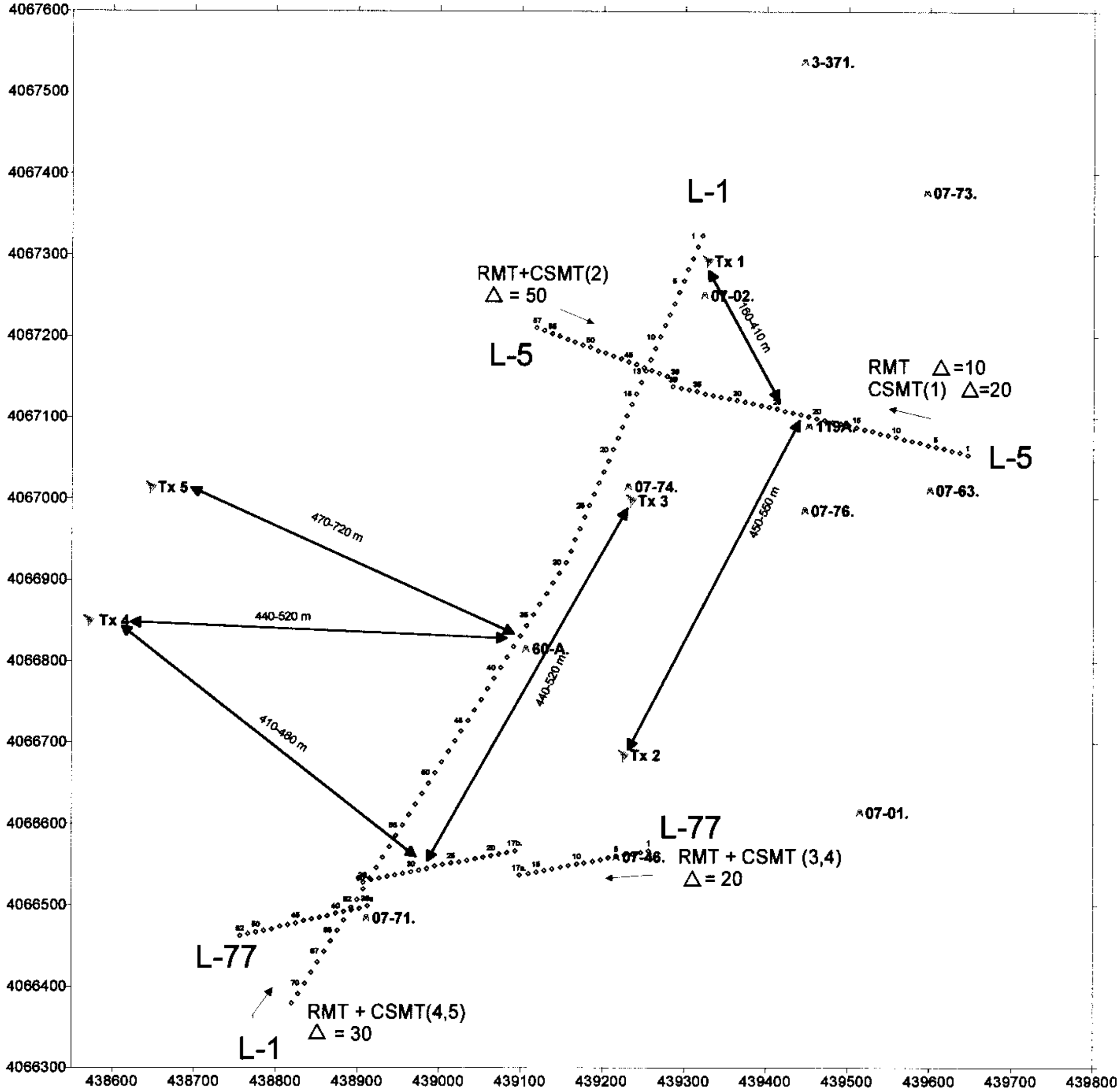
FIGURES

Computer design by Felix Rubio and Angel Pelaez

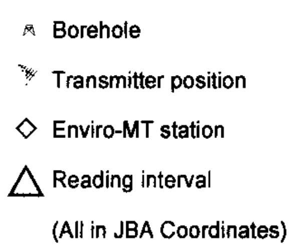


- V.E.S.
- BOREHOLE (ITGE Coordinates)
- RESISTIVITY and IP PSEUDOSECTION
- GEOELECTRIC PROFILE
- ENVIRO-MT STATIONS (JBA Coordinates).

FIGURE 1



L-1
L-5
L-77
RMT+CSMT(2)
△ = 50
RMT △=10
CSMT(1) △=20
RMT + CSMT (3,4)
△ = 20
RMT + CSMT(4,5)
△ = 30
Tx 1
Tx 2
Tx 3
Tx 4
Tx 5
180-410 m
450-550 m
470-720 m
440-520 m
440-520 m
410-480 m
3-371.
07-73.
07-02.
119A
07-63.
07-74.
07-76.
60-A
07-01.
07-46.
07-71.



Borehole
Transmitter position
Enviro-MT station
Reading interval
(All in JBA Coordinates)

FIGURE 2

Displacing the measuring point through the profile

Receiver mounted on special litter

FIGURE 3

Antenna setting in position Tx4

View of the area from Tx4

Antenna setting in position Tx1

FIGURE 4

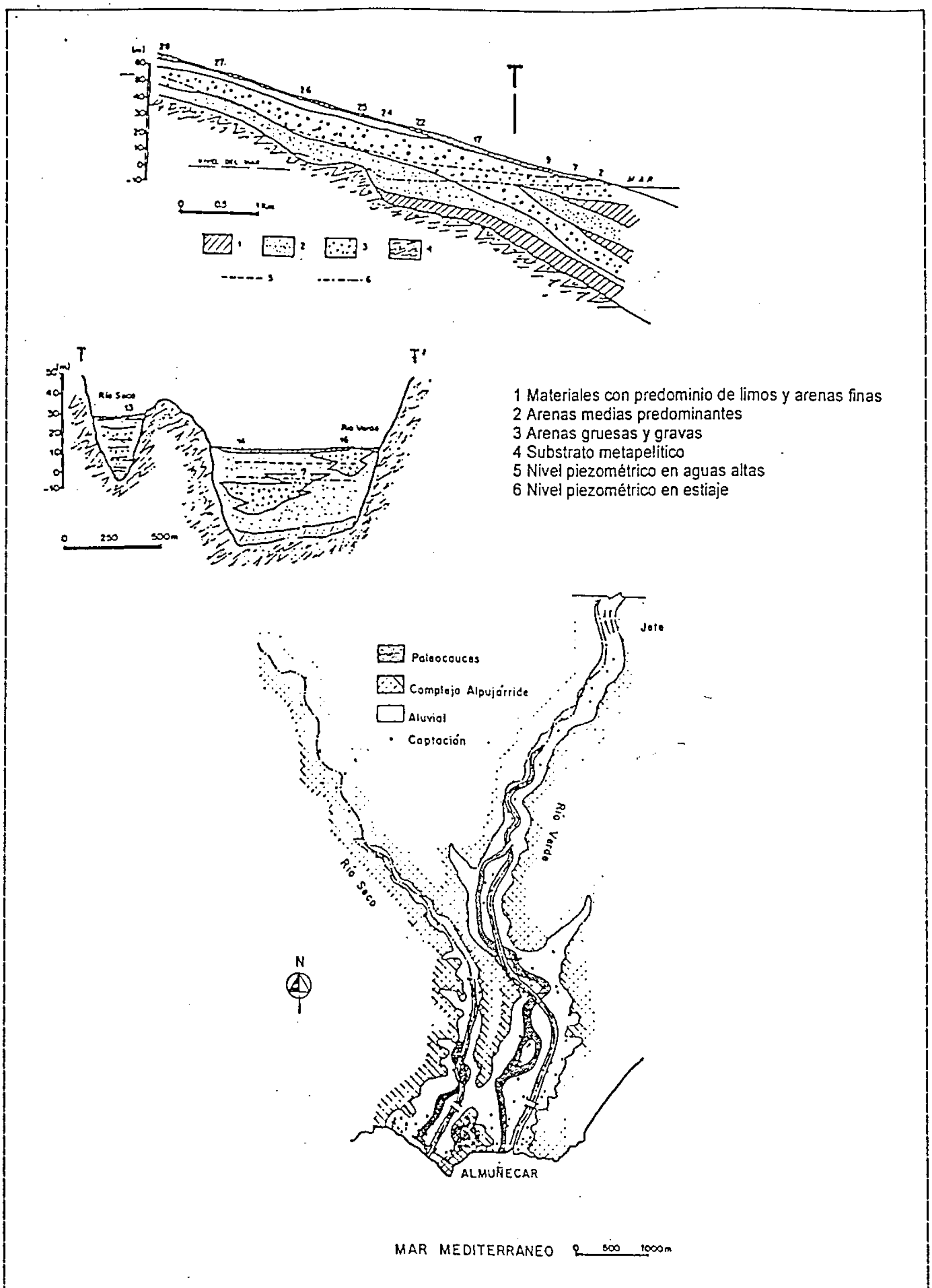
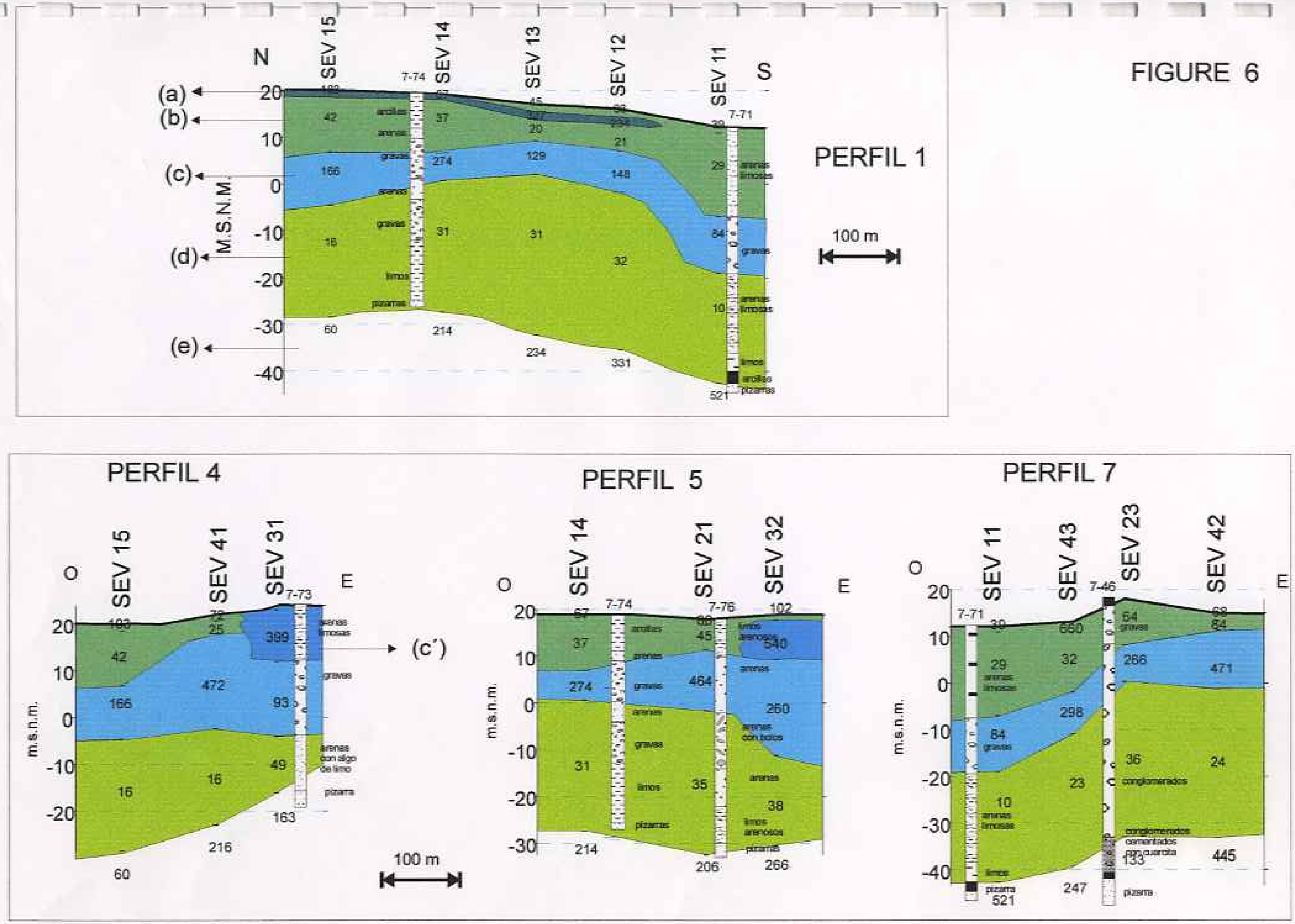

T
T'
1 Materiales con predominio de limos y arenas finas
2 Arenas medias predominantes
3 Arenas gruesas y gravas
4 Substrato metapelítico
5 Nivel piezométrico en aguas altas
6 Nivel piezométrico en estiaje
0 250 500m
Paleocauces
Complejo Alpujárride
Aluvial
Captación
Jete
Río Verde
Río Seco
N
ALMUÑECAR
MAR MEDITERRANEO
0 500 1000m

FIGURE 5

FIGURE 6


PERFIL 1
N
S
SEV 15
SEV 14
SEV 13
SEV 12
SEV 11
7-74
7-71
M.S.N.M.
(a)
(b)
(c)
(d)
(e)
100 m
PERFIL 4
SEV 15
SEV 41
SEV 31
7-73
(c´)
m.s.n.m.
PERFIL 5
SEV 14
SEV 21
SEV 32
7-74
7-76
PERFIL 7
SEV 11
SEV 43
SEV 23
SEV 42
7-71
7-46
O
E

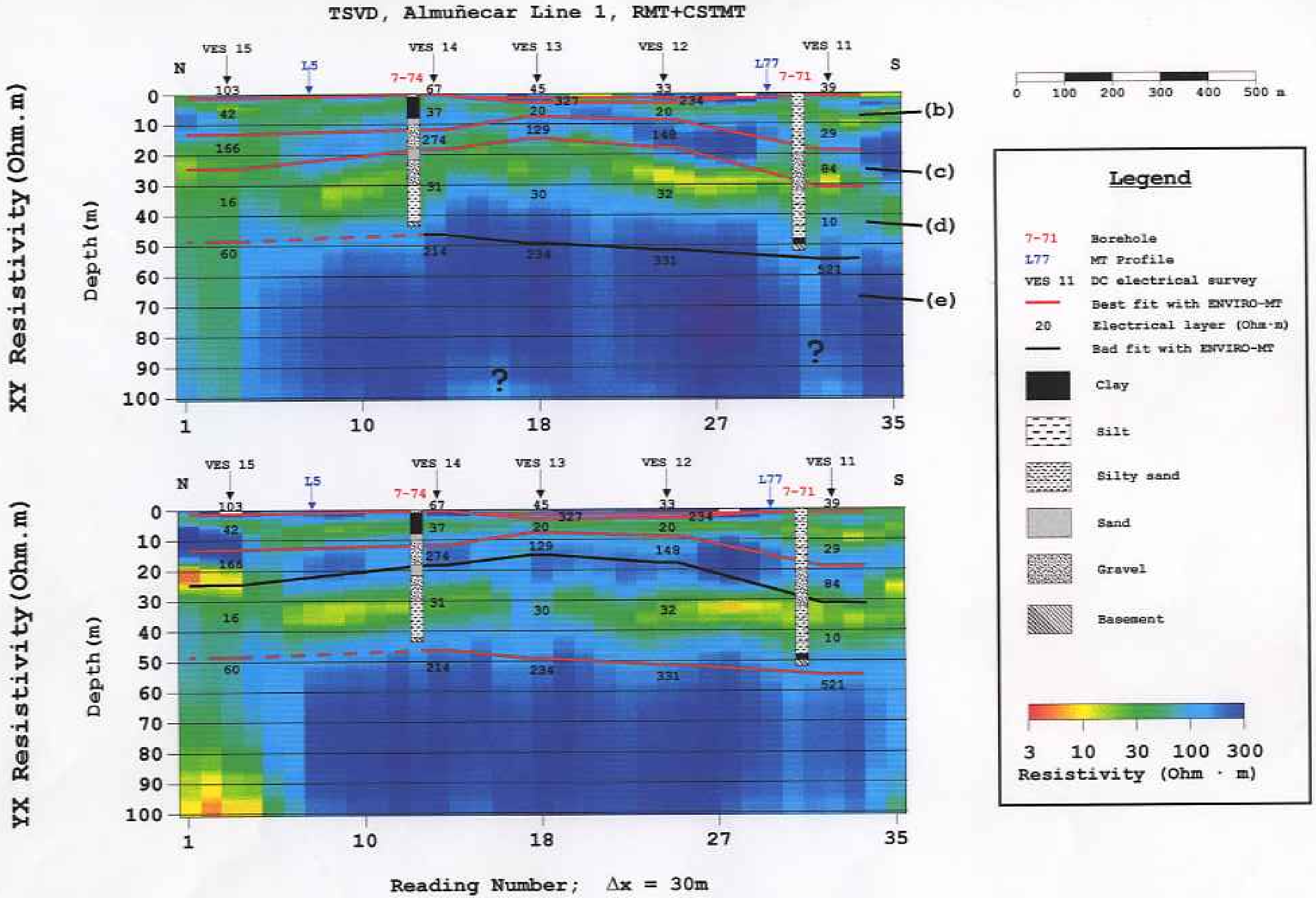

TSVD, Almuñecar Line 1, RMT+CSTMT
XY Resistivity (Ohm.m)
YX Resistivity (Ohm.m)
Depth (m)
N
S
VES 15
L5
7-74
VES 14
VES 13
VES 12
L77
7-71
VES 11
(b)
(c)
(d)
(e)
Reading Number; Δx = 30m
0 100 200 300 400 500 m
Legend
7-71 Borehole
L77 MT Profile
VES 11 DC electrical survey
Best fit with ENVIRO-MT
20 Electrical layer (Ohm·m)
Bad fit with ENVIRO-MT
Clay
Silt
Silty sand
Sand
Gravel
Basement
3 10 30 100 300
Resistivity (Ohm · m)

FIG. 7

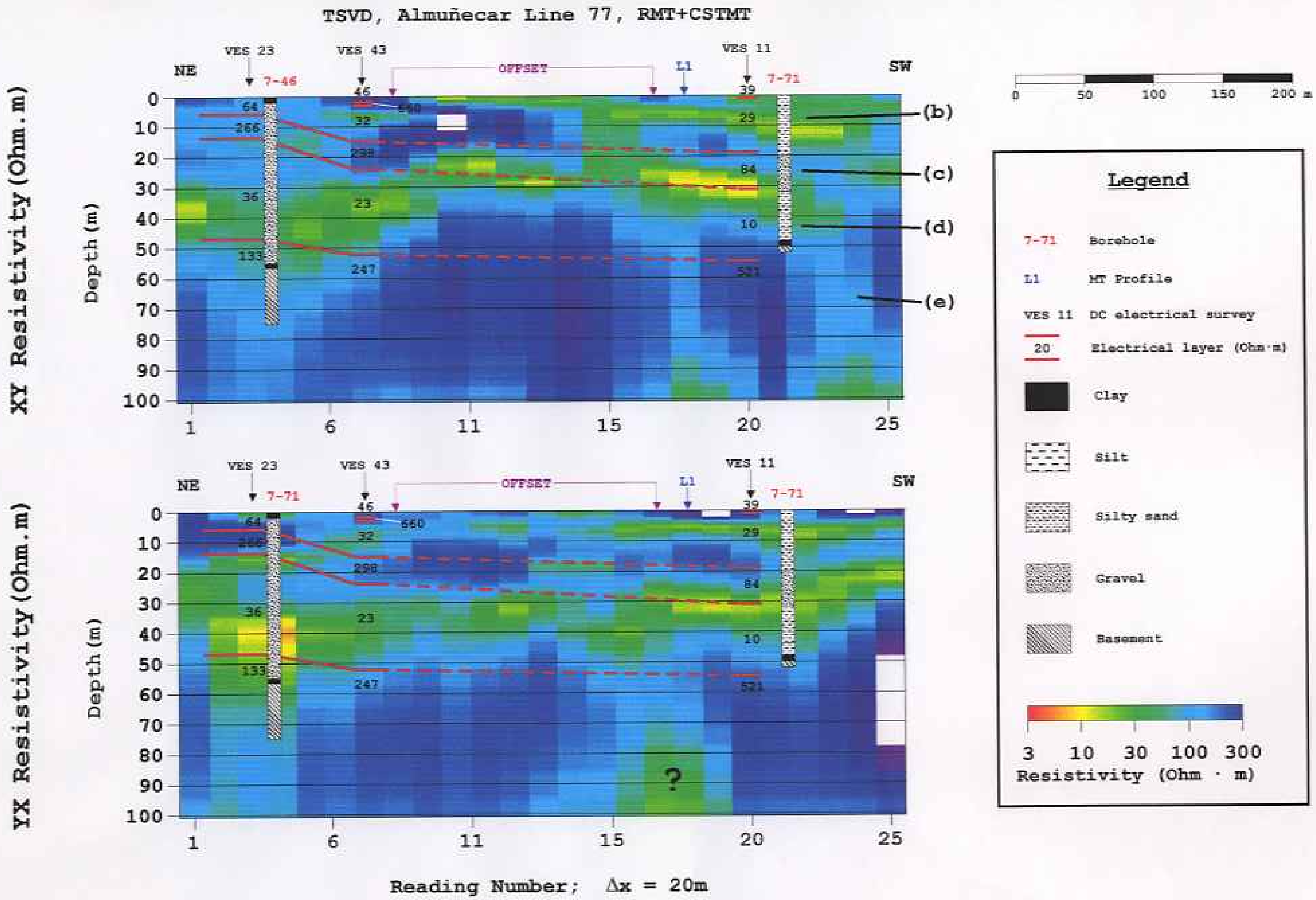

TSVD, Almuñecar Line 77, RMT+CSTMT
XY Resistivity (Ohm.m)
YX Resistivity (Ohm.m)
Depth (m)
NE
SW
VES 23
VES 43
VES 11
7-46
7-71
OFFSET
L1
(b)
(c)
(d)
(e)
?
Reading Number; Δx = 20m
0 50 100 150 200 m
Legend
7-71 Borehole
L1 MT Profile
VES 11 DC electrical survey
20 Electrical layer (Ohm·m)
Clay
Silt
Silty sand
Gravel
Basement
3 10 30 100 300
Resistivity (Ohm · m)

FIG. 8

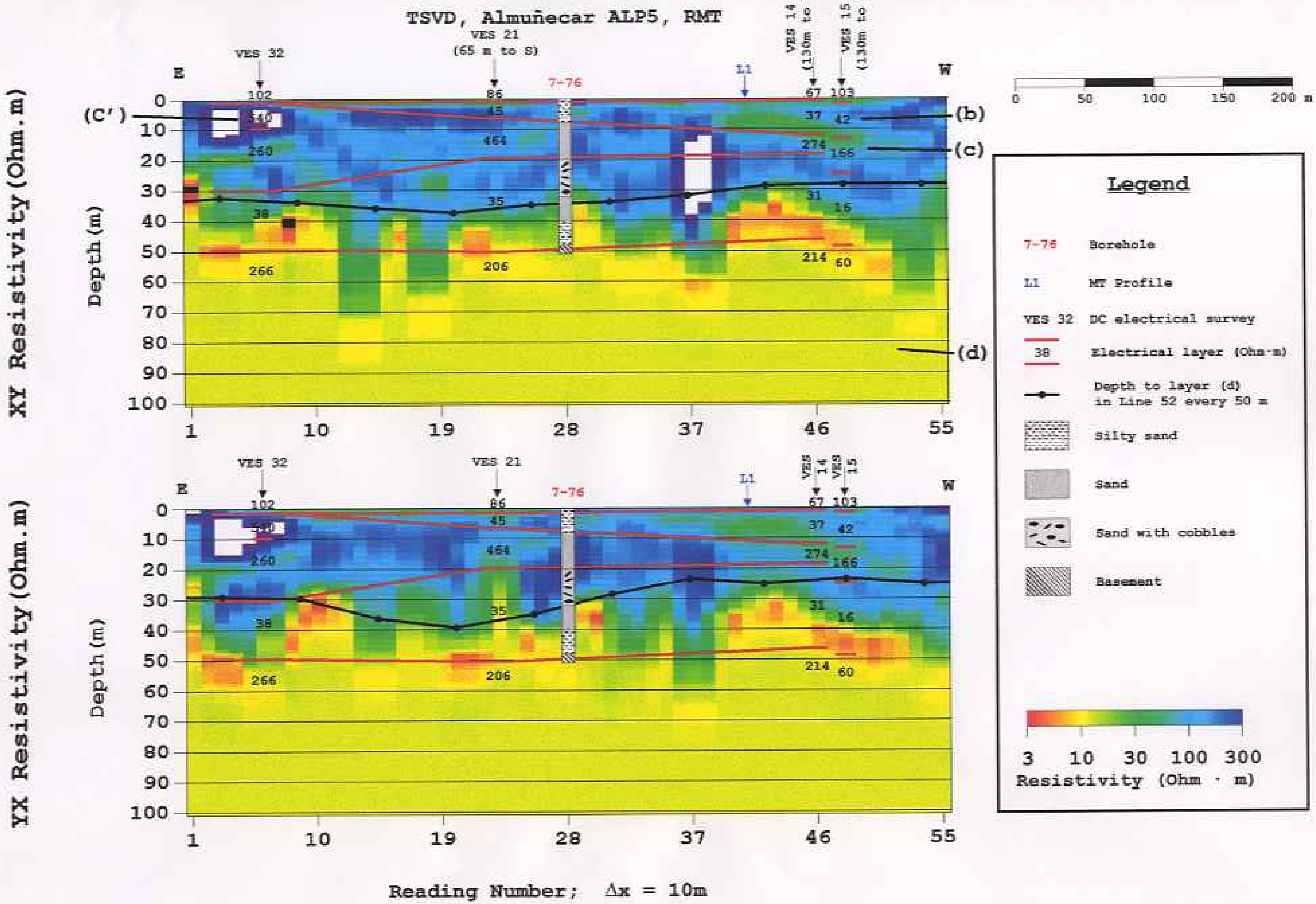

TSVD, Almuñecar ALP5, RMT
VES 32
VES 21
(65 m to S)
7-76
L1
VES 14
(130m to S)
VES 15
(130m to N)
E
W
(C')
(b)
(c)
(d)
XY Resistivity (Ohm.m)
YX Resistivity (Ohm.m)
Depth (m)
Reading Number; Δx = 10m
0
50
100
150
200 m
Legend
7-76 Borehole
L1 MT Profile
VES 32 DC electrical survey
38 Electrical layer (Ohm·m)
Depth to layer (d) in Line 52 every 50 m
Silty sand
Sand
Sand with cobbles
Basement
3 10 30 100 300
Resistivity (Ohm · m)

FIG. 9

ANNEXO I

Proposed planning for the ENVIRO-MT test in Almuñecar. April 1999.

PLANNING OF THE ENVIRO-MT TEST SURVEY

Three transversal profiles P5, P6 and P7 of about 600 m each (with some lateral variation in the resistivity distribution), and two longitudinal profiles P1 and P2 of 1000 m each (which are more homogeneous) are proposed to be measured in Almuñecar test site, in the position shown in fig. 29, keeping the transmitter antenna in the situation W. Another measurements will be taken, in order to better analyze the instrument and the field methodology.

The average production rate estimated is of 10 readings per hour.

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, 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.

The complete set of ENVIRO-MT measurements taken on the three transversal profiles (P5, P6 and P7), and the two longitudinal ones (P1 and P2), will form the bases for this analysis. The results will be compared with the geological information previously available from the VES survey, mechanical drillings, and the resistivity pseudosection measured with dc and a dipole-dipole array every 50 m. Quality of the information obtained, as well as the time required and the difficulties found in the field work with each operative system (ENVIRO, VES and DC Profiling) will be evaluated.

. 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.

2/ REPEATABILITY AND PRODUCTIVITY TEST

. One of the transversal profiles (P5, P6 or P7), will be measured twice, with the same reading parameters, but following two different operational systems: first time with one receiver operator and two helpers for the displacement of the instrument through 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 set of measurements will allow to:

. compare the repeatability of the results with statistical support.

. compare the production rates which can be achieved

The additional readings needed for this tests are:

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

60 readings/profile = 6 h/profile

3/ HORIZONTAL RESOLUTION TEST

. Once several profiles have been measured, two zones of 50 m with lateral changes will be selected. The test consists in taking new readings on this zone, with a distance of 5 m between them. The eastern portions of P5 or P6 seems in first instance to be appropriate to do this test.

. additional readings to take: 20 (2 h)

4/ TRANSMITTER POSITION DEPENDENCE TEST

. Two portions of about 100 m for one of the profiles in each direction will be measured again with the transmitter located in position North. P5 and the northern part of P1 and P2 are good areas for this test.

. additional readings to take: 20 (2 h)

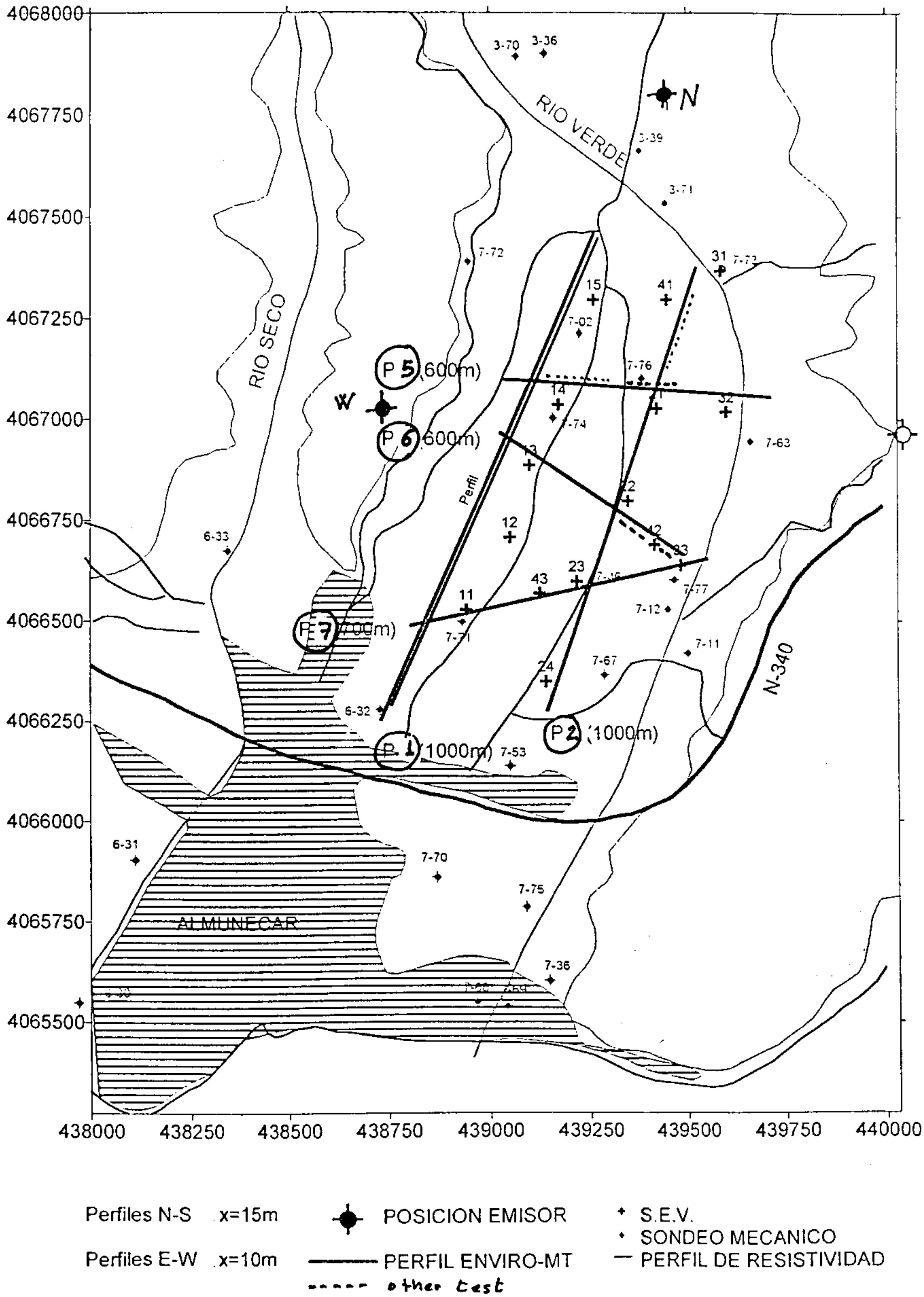

4068000
4067750
4067500
4067250
4067000
4066750
4066500
4066250
4066000
4065750
4065500
438000
438250
438500
438750
439000
439250
439500
439750
440000
RIO SECO
RIO VERDE
N-340
ALMUNECAR
N
W
P 5 (600m)
P 6 (600m)
P 7 (700m)
P 1 (1000m)
P 2 (1000m)
Perfil
3-70
3-36
3-39
3-71
7-72
7-73
31
15
41
7-02
7-76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

FIGURA 29

ANNEXO II

. List of coordinates supplied by JBA
. Plot of this list
. Final position map supplied by JBA on july 1999

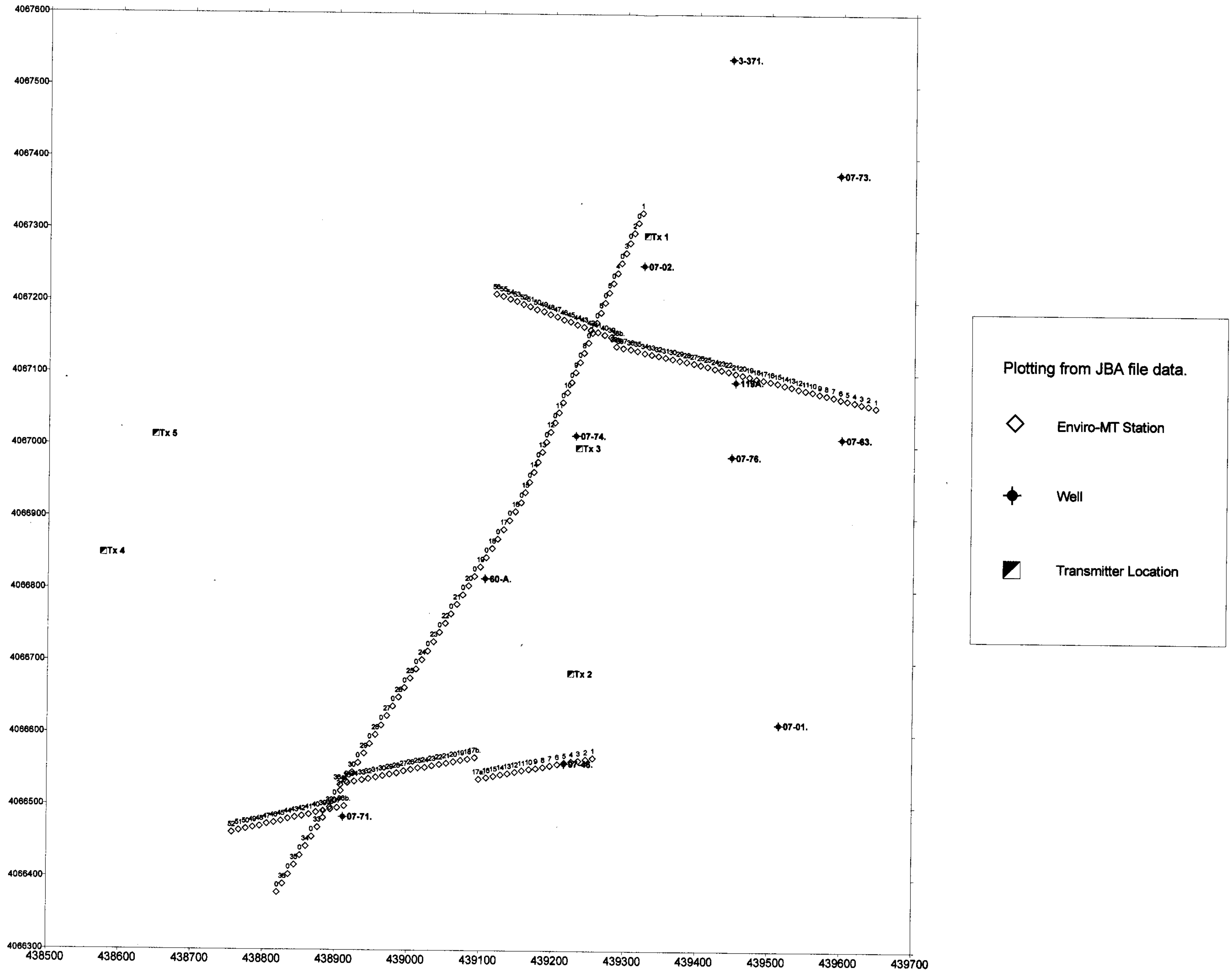
On JBA map the number of the stations for the crossing points of profiles, offset stations, and road crossings, differs from the described ones in this Report, which are the real field situation; there is also some discrepancies in the labelling of stations in regard with the really one used in the field.

Station	X	Y	Z
Line 1			
1	439321.4	4067324	
0	439315.7	4067310	
2	439309.9	4067296	
0	439304.2	4067282	23.74
3	439298.5	4067268	
0	439292.8	4067254	
4	439287	4067240	23
0	439281.3	4067226	
5	439275.5	4067213	
0	439269.8	4067199	22.35
6	439264.1	4067185	
0	439258.3	4067171	21.06
7	439252.6	4067157	
0	439246.8	4067143	
8	439241.1	4067129	
0	439235.4	4067116	20.79
9	439229.6	4067102	
0	439223.9	4067088	
10	439218.2	4067074	19.3
0	439212.4	4067060	
11	439206.7	4067046	
0	439201	4067032	19.9
12	439195.2	4067019	
0	439189.5	4067005	
13	439183.8	4066991	19.36
0	439178	4066977	
14	439172.3	4066963	18.87
0	439166.5	4066949	
15	439160.8	4066935	
0	439155	4066921	18.56
16	439147.1	4066908	
0	439139.1	4066896	
17	439131.1	4066883	18.11
0	439123.1	4066870	
18	439115.2	4066857	
0	439107.2	4066844	17.83
19	439099.2	4066831	
0	439091.2	4066818	
20	439083.2	4066805	18.05
0	439075.2	4066792	
21	439067.2	4066779	
0	439059.2	4066766	16.65
22	439051.3	4066753	
0	439043.3	4066740	
23	439035.3	4066727	15.89
0	439027.3	4066714	
24	439019.3	4066702	
0	439011.3	4066689	15.38
25	439003.3	4066676	
0	438995.3	4066663	
26	438987.4	4066650	14.84
0	438979.3	4066637	
27	438971.3	4066624	
0	438963.3	4066611	14.18
28	438955.4	4066598	
0	438947.4	4066585	
29	438939.4	4066572	13.92
0	438931.4	4066559	
30	438923.4	4066546	
0	438915.4	4066533	13.49
31	438907.4	4066520	

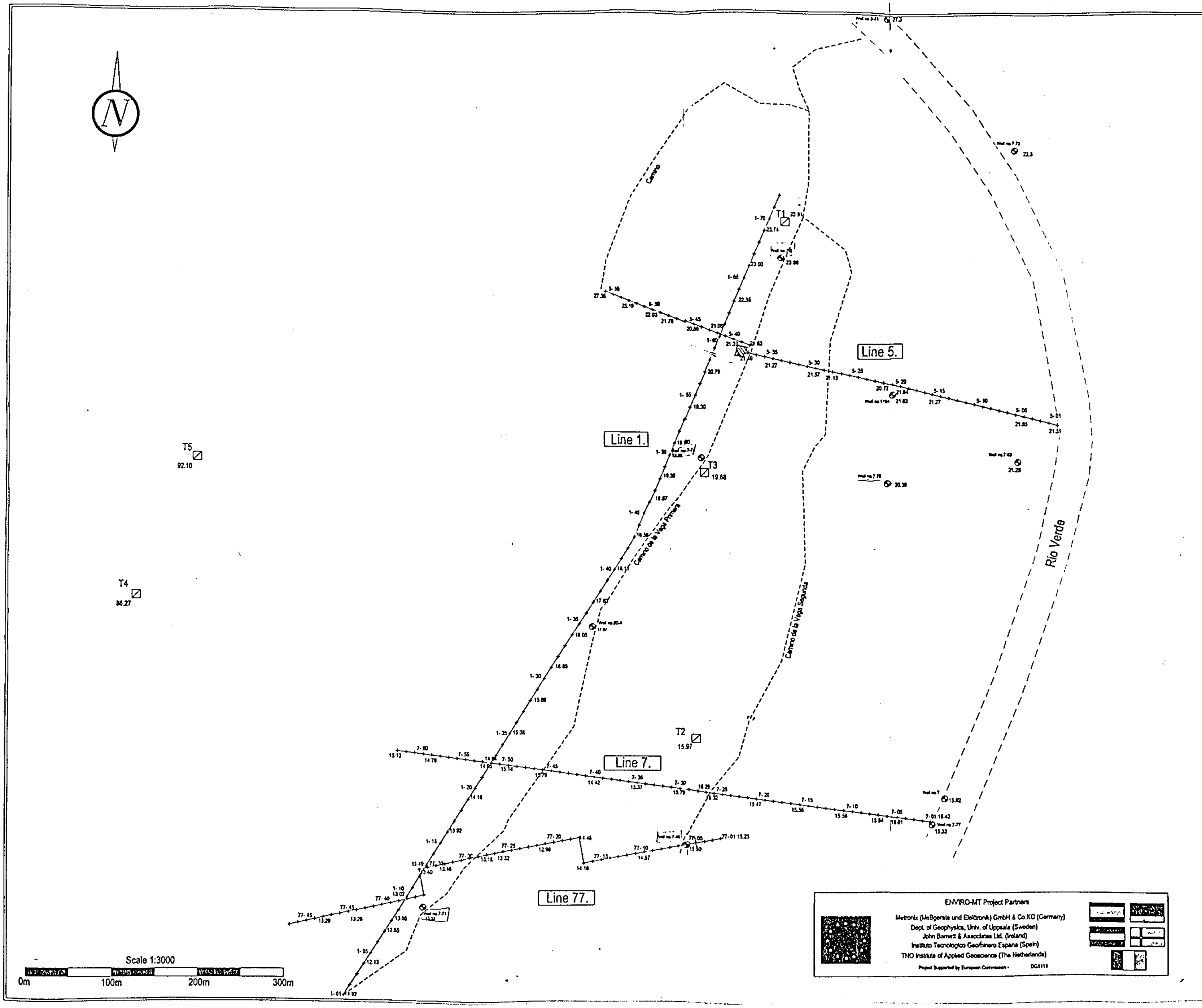
0	438899.5	4066507	
32	438892.6	4066497	13.02
0	438883.5	4066482	
33	438875.5	4066469	13.06
0	438867.5	4066456	12.85
34	438859.5	4066443	
0	438851.5	4066430	
35	438843.5	4066417	12.13
0	438835.6	4066404	
36	438827.6	4066391	
0	438819.9	4066379	11.92
Line 77			
1	439256.7	4066567	15.23
2	439246.9	4066565	
3	439237	4066563	
4	439227.2	4066562	
5	439217.3	4066560	15.5
6	439207.6	4066558	
7	439197.7	4066556	
8	439187.9	4066554	
9	439178	4066552	
10	439168.5	4066551	14.57
11	439158.4	4066549	
12	439148.6	4066547	
13	439138.7	4066545	
14	439128.9	4066543	
15	439119.1	4066541	
16	439109.3	4066539	
17a.	439098.8	4066537	14.16
17b.	439093.2	4066567	14.48
18	439083.3	4066565	
19	439073.5	4066563	
20	439063.7	4066561	
21	439053.9	4066559	12.99
22	439044.1	4066557	
23	439034.2	4066555	
24	439024.4	4066553	
25	439014.6	4066552	
26	439004.8	4066550	13.32
27	438995	4066548	
28	438985.2	4066545	13.18
29	438975.5	4066543	
30	438965.7	4066541	
31	438955.9	4066539	
32	438946.2	4066537	
33	438937	4066535	13.46
34	438926.6	4066533	13.4
35	438916.8	4066531	
36a.	438907.1	4066528	13.49
36b.	438912.7	4066499	
37	438902.9	4066496	
38	438893.2	4066494	
39	438883.4	4066492	
40	438873.7	4066490	13.06
41	438863.8	4066487	
42	438854.2	4066485	
43	438844.4	4066483	
44	438834.7	4066481	13.26
45	438824.9	4066478	
46	438815.2	4066476	
47	438805.5	4066474	
48	438795.6	4066471	13.29
49	438786	4066469	
50	438776.3	4066467	

51	438766.5	4066465	
52	438756.8	4066462	
Line 5			
1	439646	4067054	21.51
2	439636.2	4067057	
3	439626.4	4067059	
4	439616.7	4067062	
5	439607	4067064	21.65
6	439597.3	4067066	
7	439587.5	4067069	
8	439577.8	4067071	
9	439568.3	4067073	
10	439558.5	4067076	
11	439548.8	4067078	
12	439539.1	4067080	
13	439529.3	4067083	
14	439519.6	4067085	
15	439509.9	4067088	21.27
16	439500.2	4067090	
17	439490.5	4067092	
18	439480.7	4067094	
19	439471	4067097	
20	439461.3	4067099	21.84
21	439451.5	4067101	
22	439441.8	4067104	20.77
23	439432.1	4067106	
24	439422.5	4067108	
25	439412.7	4067111	
26	439402.8	4067113	
27	439393.2	4067115	
28	439383.3	4067117	21.13
29	439373.5	4067119	
30	439363.7	4067121	21.57
31	439354	4067123	
32	439344.2	4067125	
33	439334.4	4067127	
34	439324.6	4067129	
35	439314.9	4067132	21.27
36	439305.2	4067134	
37	439295.4	4067136	
38a.	439285.6	4067138	21.49
38b.	439288	4067147	21.63
39	439278.3	4067151	
40	439268.9	4067154	21.37
41	439259.5	4067158	
42	439250.1	4067161	
43	439240.7	4067165	
44	439231.3	4067168	
45	439222	4067172	20.88
46	439212.5	4067175	
47	439203.2	4067179	
48	439193.8	4067182	21.78
49	439184.5	4067186	
50	439175.1	4067189	22.03
51	439165.7	4067193	
52	439156.3	4067196	
53	439146.9	4067200	25.19
54	439137.6	4067203	
55	439128.2	4067207	
56	439118.8	4067210	27.36
nsmitter position			
1	439328	4067292	23.9
2	439226	4066684	15.9
3	439235	4066997	24.68

4	438576	4066849	86.3
5	438647	4067013	92.1
Wells			
3-371.	439446	4067538	27.3
07-73.	439596	4067377	22.5
07-02.	439324	4067250	23.9
119A.	439452	4067089	21.6
07-74.	439231	4067014	19.9
07-76.	439447	4066985	20.4
07-63.	439600	4067010	21.3
60-A.	439106	4066815	17.9
07-01.	439515	4066614	15.3
07-46.	439217	4066559	15.5
07-71.	438911	4066484	13.5



Plotting from JBA file data.
Enviro-MT Station
Well
Transmitter Location
Tx 1
Tx 2
Tx 3
Tx 4
Tx 5
3-371.
07-73.
07-02.
07-74.
07-76.
07-63.
07-01.
60-A.
07-71.
4067600
4067500
4067400
4067300
4067200
4067100
4067000
4066900
4066800
4066700
4066600
4066500
4066400
4066300
438500
438600
438700
438800
438900
439000
439100
439200
439300
439400
439500
439600
439700



Notes

1). Survey Undertaken between the 13th and 23rd of April 1999.

2). The Position of the Roads and River are shown approximately only.

Legend

- · - · -	Dry River Bed
- - - - -	Road
———	Measurement Line
T2 ☒	Transmitter Location
5-05	Station No.
⊗	Well
21.85	Elevation

Ref.No.	Date	Amendments	By	Chk'd
REV.A	July 99	Lines	TF	

CLIENT: ENVIRO-MT Project Team

PROJECT: Geophysical Survey: Almuñecar Spain

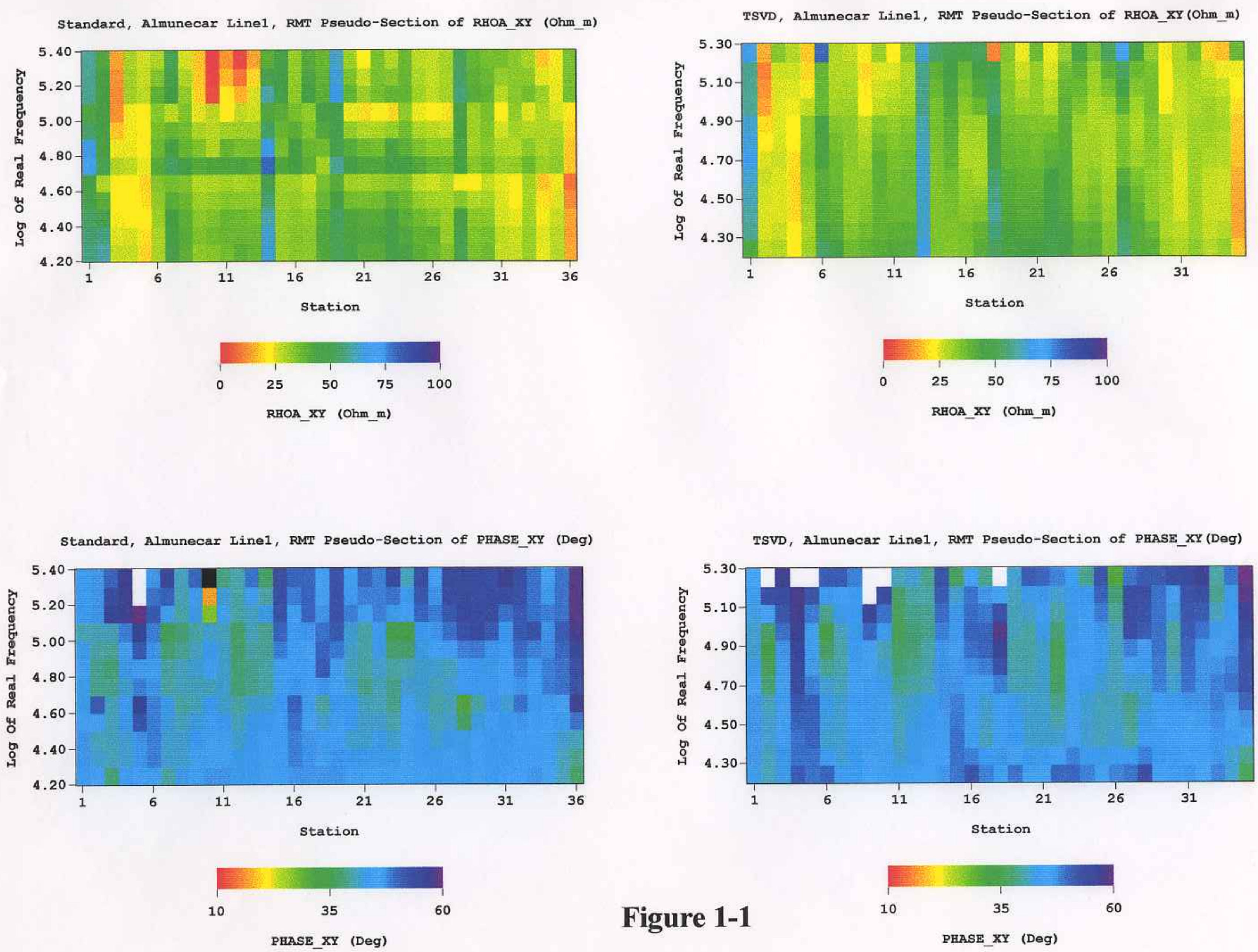
TITLE: Site Plan

John Barnett & Associates
Chartered Mineral Surveyors, Minerals, Environmental, Geotechnical Consultants.
Unit 7, CSA House, Dundrum Business Pk, Windy Arbour, Dublin 14, Ireland.

Scale	1:3000	Datum	O.D.
Date	July 1999		
Author	JBA	Drawing No.	JBA_348_D02
Drawn by	TF	Ref	JBA_348

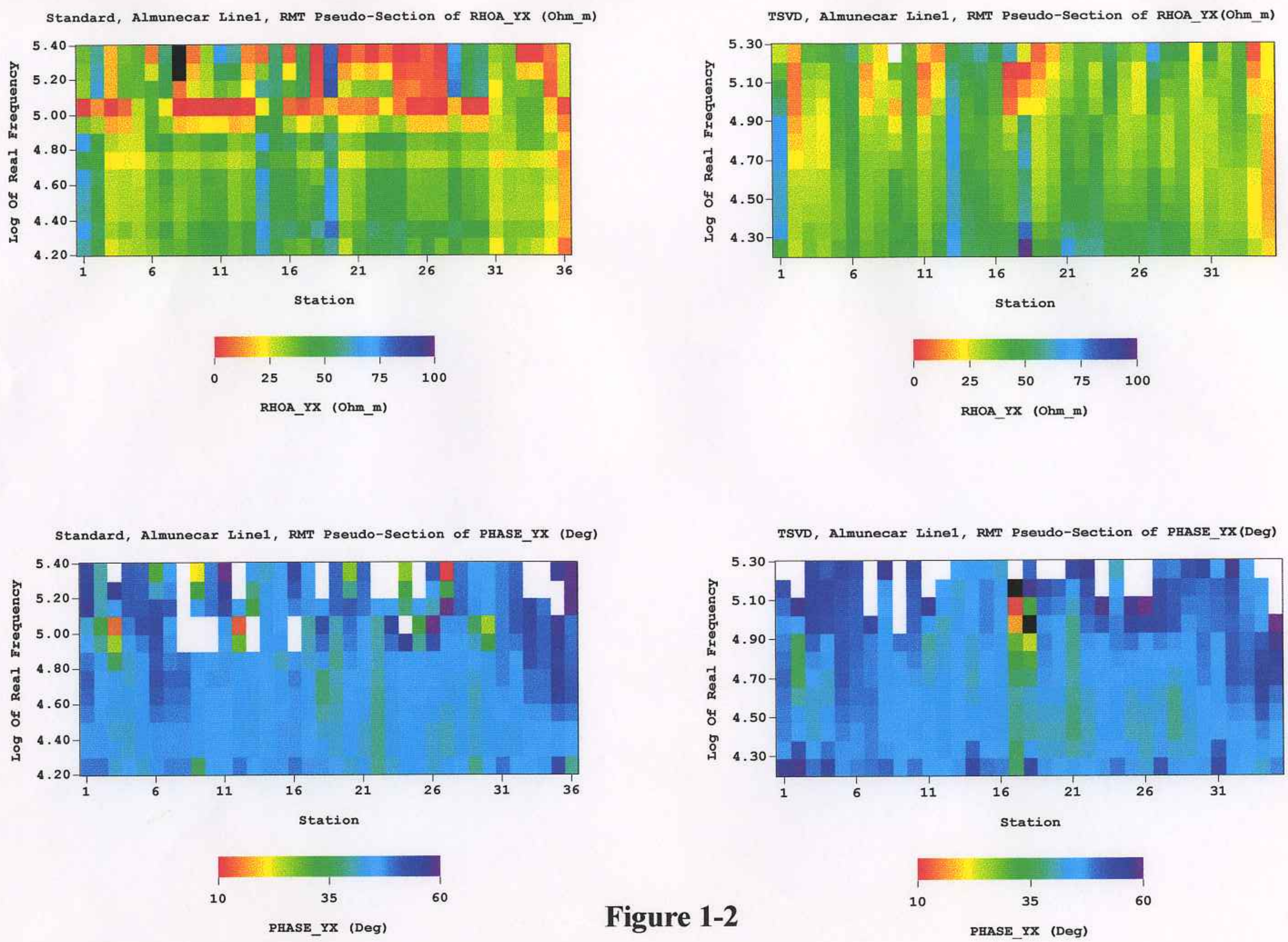
ANNEXO III

ENVIRO-MT sections received from Uppsala University.



Standard, Almunecar Line1, RMT Pseudo-Section of RHOA_XY (Ohm_m)
Log Of Real Frequency
Station
RHOA_XY (Ohm_m)
TSVD, Almunecar Line1, RMT Pseudo-Section of RHOA_XY(Ohm_m)
Log Of Real Frequency
Station
RHOA_XY (Ohm_m)
Standard, Almunecar Line1, RMT Pseudo-Section of PHASE_XY (Deg)
Log Of Real Frequency
Station
PHASE_XY (Deg)
TSVD, Almunecar Line1, RMT Pseudo-Section of PHASE_XY(Deg)
Log Of Real Frequency
Station
PHASE_XY (Deg)

Figure 1-1



Standard, Almunecar Line1, RMT Pseudo-Section of RHOA_YX (Ohm_m)
Log Of Real Frequency
5.40
5.20
5.00
4.80
4.60
4.40
4.20
1
6
11
16
21
26
31
36
Station
0
25
50
75
100
RHOA_YX (Ohm_m)
TSVD, Almunecar Line1, RMT Pseudo-Section of RHOA_YX(Ohm_m)
Log Of Real Frequency
5.30
5.10
4.90
4.70
4.50
4.30
1
6
11
16
21
26
31
Station
0
25
50
75
100
RHOA_YX (Ohm_m)
Standard, Almunecar Line1, RMT Pseudo-Section of PHASE_YX (Deg)
Log Of Real Frequency
5.40
5.20
5.00
4.80
4.60
4.40
4.20
1
6
11
16
21
26
31
36
Station
10
35
60
PHASE_YX (Deg)
TSVD, Almunecar Line1, RMT Pseudo-Section of PHASE_YX(Deg)
Log Of Real Frequency
5.30
5.10
4.90
4.70
4.50
4.30
1
6
11
16
21
26
31
Station
10
35
60
PHASE_YX (Deg)

Figure 1-2

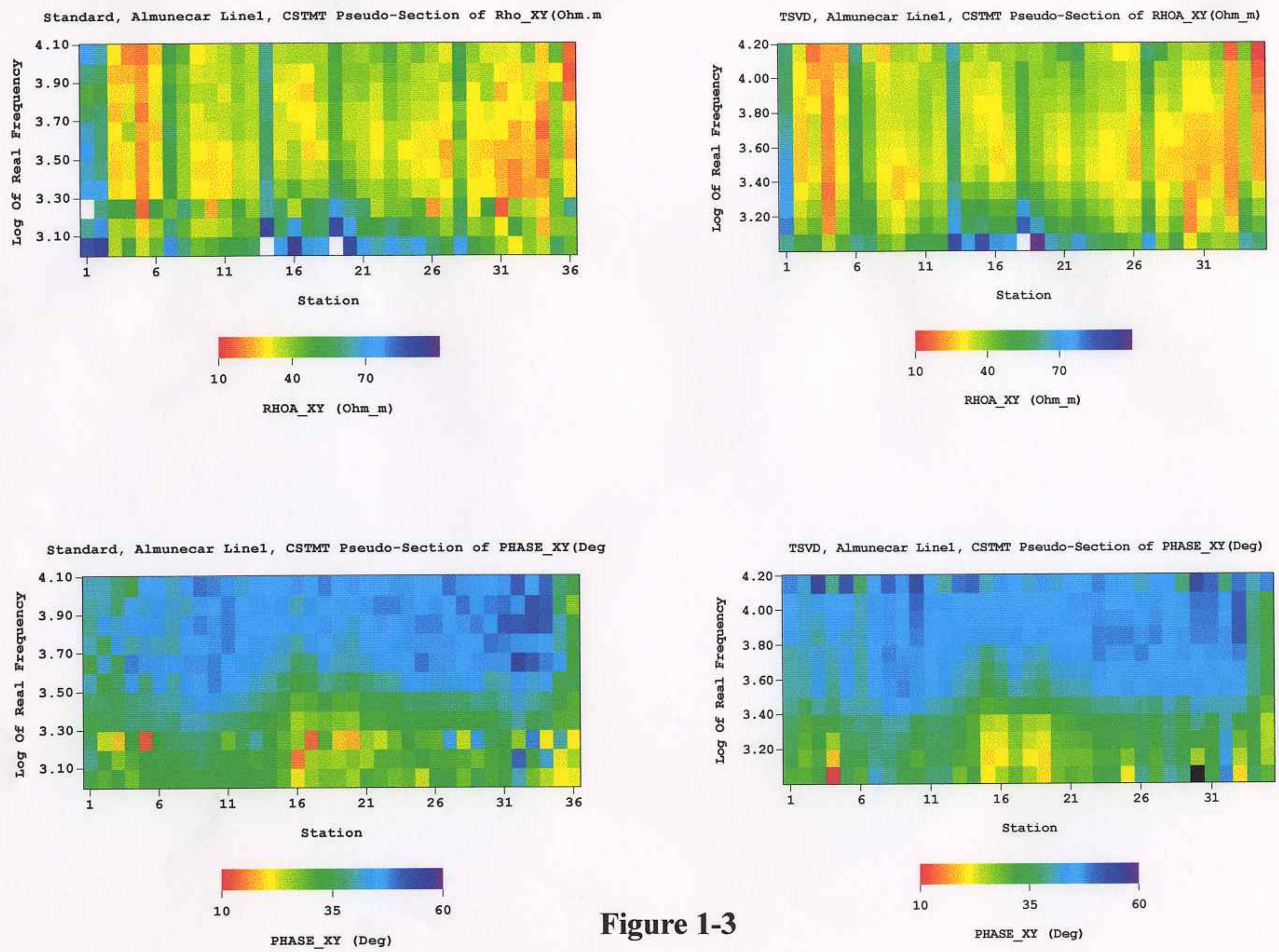

Standard, Almunecar Line1, CSTMT Pseudo-Section of Rho_XY(Ohm.m
Log Of Real Frequency
4.10
3.90
3.70
3.50
3.30
3.10
1
6
11
16
21
26
31
36
Station
10
40
70
RHOA_XY (Ohm_m)
TSVD, Almunecar Line1, CSTMT Pseudo-Section of RHOA_XY(Ohm_m)
Log Of Real Frequency
4.20
4.00
3.80
3.60
3.40
3.20
1
6
11
16
21
26
31
Station
10
40
70
RHOA_XY (Ohm_m)
Standard, Almunecar Line1, CSTMT Pseudo-Section of PHASE_XY(Deg
Log Of Real Frequency
4.10
3.90
3.70
3.50
3.30
3.10
1
6
11
16
21
26
31
36
Station
10
35
60
PHASE_XY (Deg)
TSVD, Almunecar Line1, CSTMT Pseudo-Section of PHASE_XY(Deg)
Log Of Real Frequency
4.20
4.00
3.80
3.60
3.40
3.20
1
6
11
16
21
26
31
Station
10
35
60
PHASE_XY (Deg)

Figure 1-3

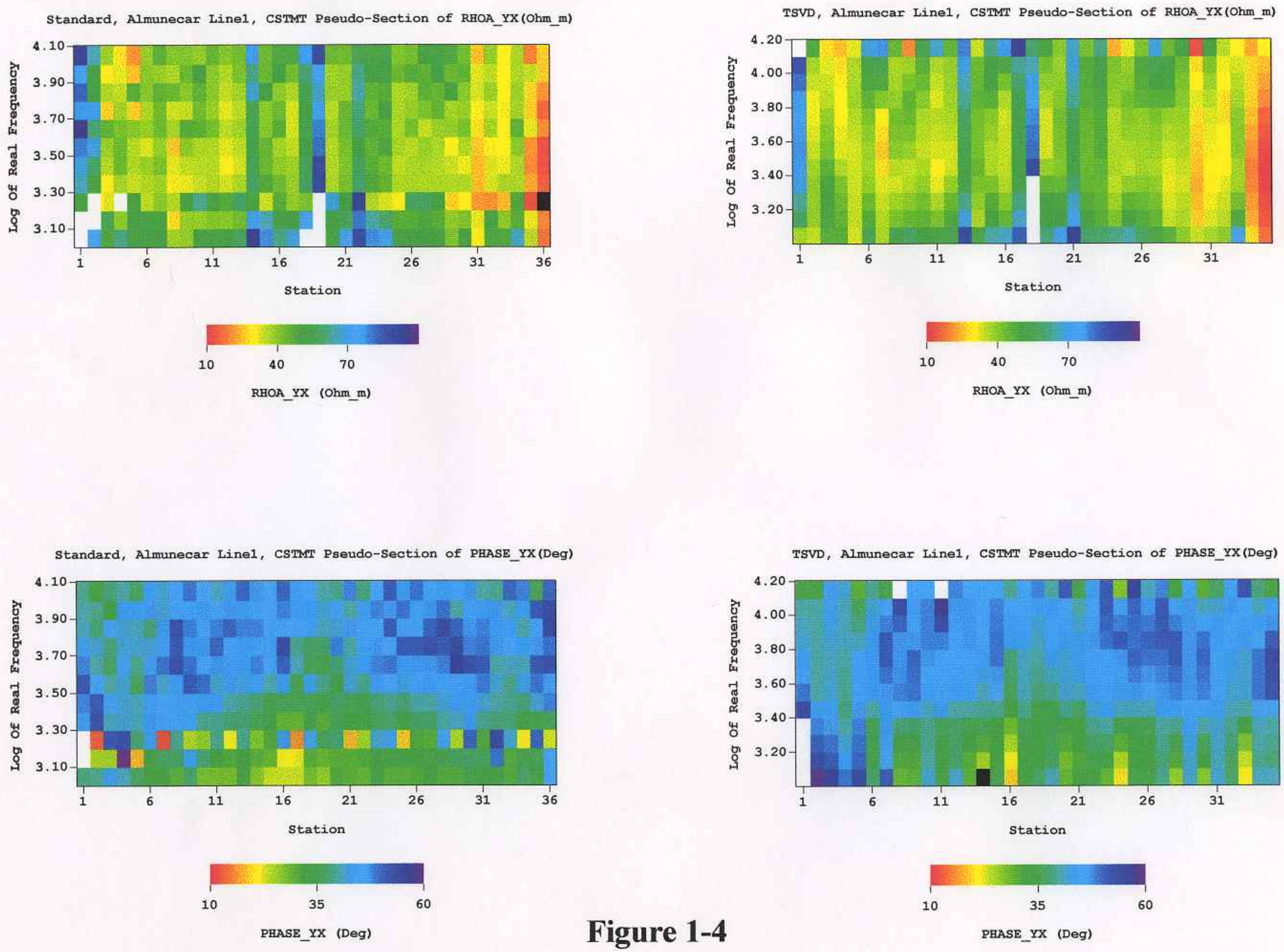

Standard, Almunecar Line1, CSTMT Pseudo-Section of RHOA_YX(Ohm_m)
Log Of Real Frequency
4.10
3.90
3.70
3.50
3.30
3.10
1
6
11
16
21
26
31
36
Station
10
40
70
RHOA_YX (Ohm_m)
TSVD, Almunecar Line1, CSTMT Pseudo-Section of RHOA_YX(Ohm_m)
Log Of Real Frequency
4.20
4.00
3.80
3.60
3.40
3.20
1
6
11
16
21
26
31
Station
10
40
70
RHOA_YX (Ohm_m)
Standard, Almunecar Line1, CSTMT Pseudo-Section of PHASE_YX(Deg)
Log Of Real Frequency
4.10
3.90
3.70
3.50
3.30
3.10
1
6
11
16
21
26
31
36
Station
10
35
60
PHASE_YX (Deg)
TSVD, Almunecar Line1, CSTMT Pseudo-Section of PHASE_YX(Deg)
Log Of Real Frequency
4.20
4.00
3.80
3.60
3.40
3.20
1
6
11
16
21
26
31
Station
10
35
60
PHASE_YX (Deg)

Figure 1-4

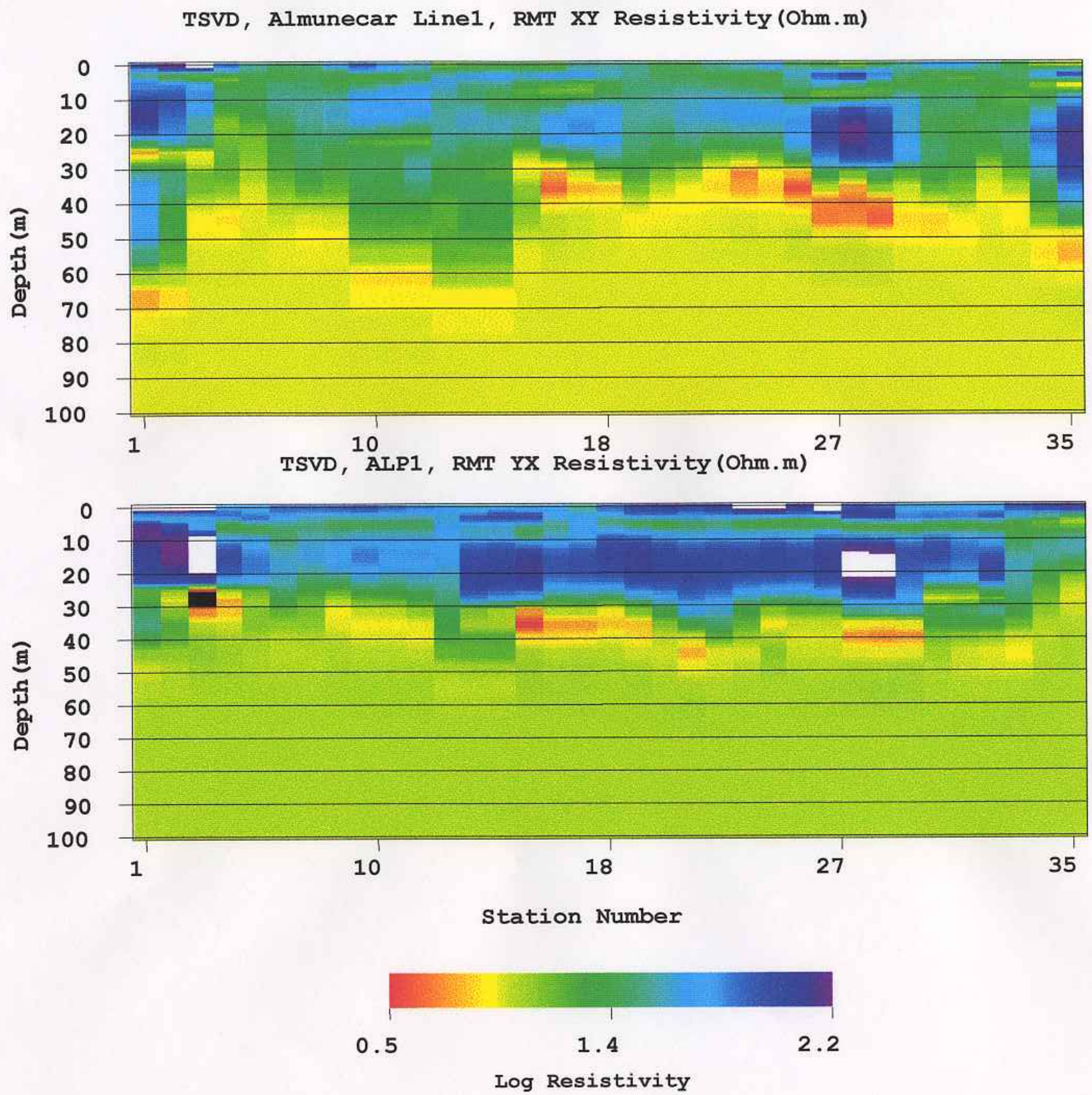

TSVD, Almunecar Line1, RMT XY Resistivity (Ohm.m)
Depth (m)
0
10
20
30
40
50
60
70
80
90
100
1
10
18
27
35
TSVD, ALP1, RMT YX Resistivity (Ohm.m)
Depth (m)
Station Number
0.5
1.4
2.2
Log Resistivity

Figure 1-5

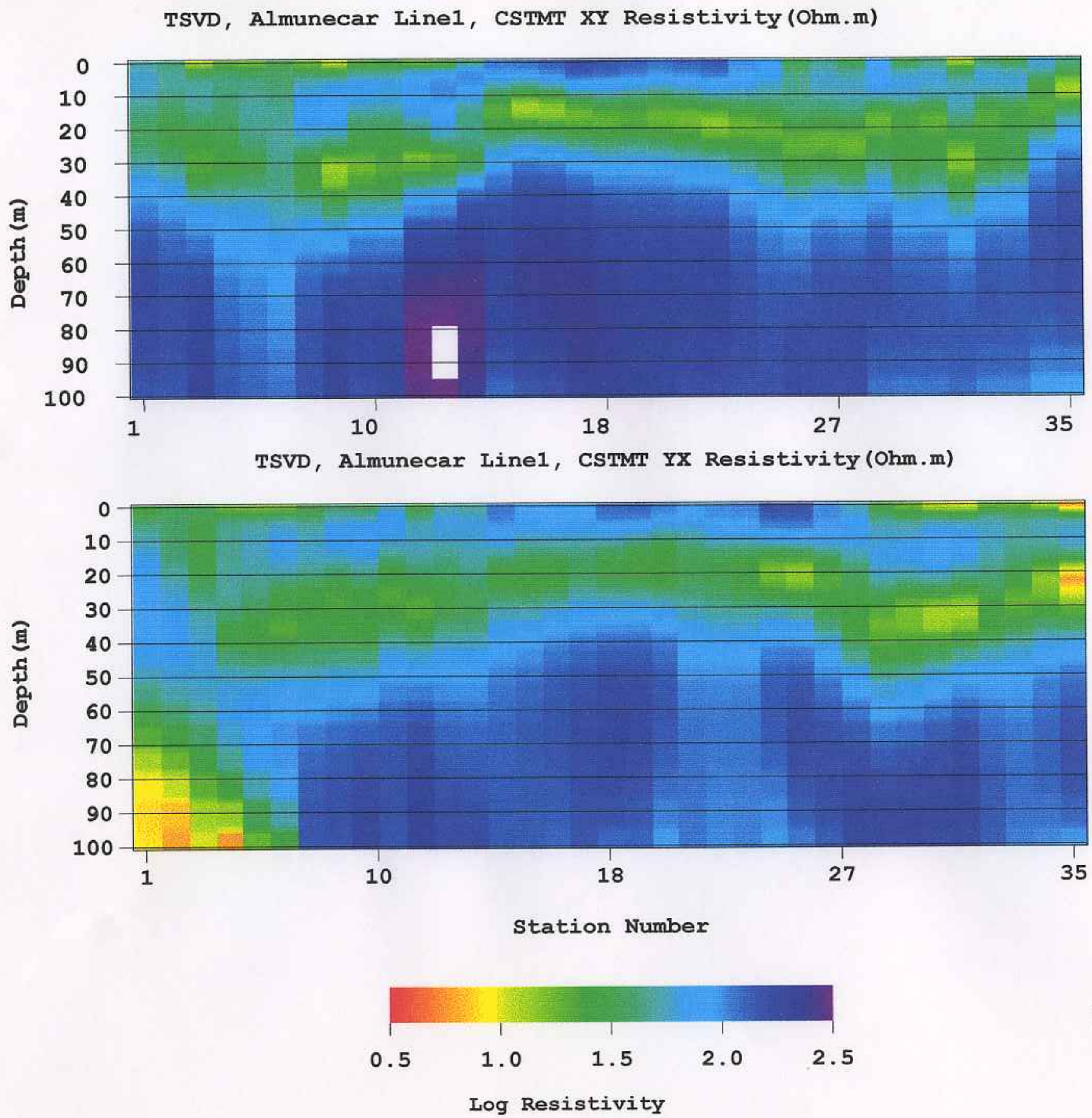

TSVD, Almunecar Line1, CSTMT XY Resistivity(Ohm.m)
Depth (m)
0
10
20
30
40
50
60
70
80
90
100
1
10
18
27
35
TSVD, Almunecar Line1, CSTMT YX Resistivity(Ohm.m)
Depth (m)
Station Number
0.5
1.0
1.5
2.0
2.5
Log Resistivity

Figure 1-6

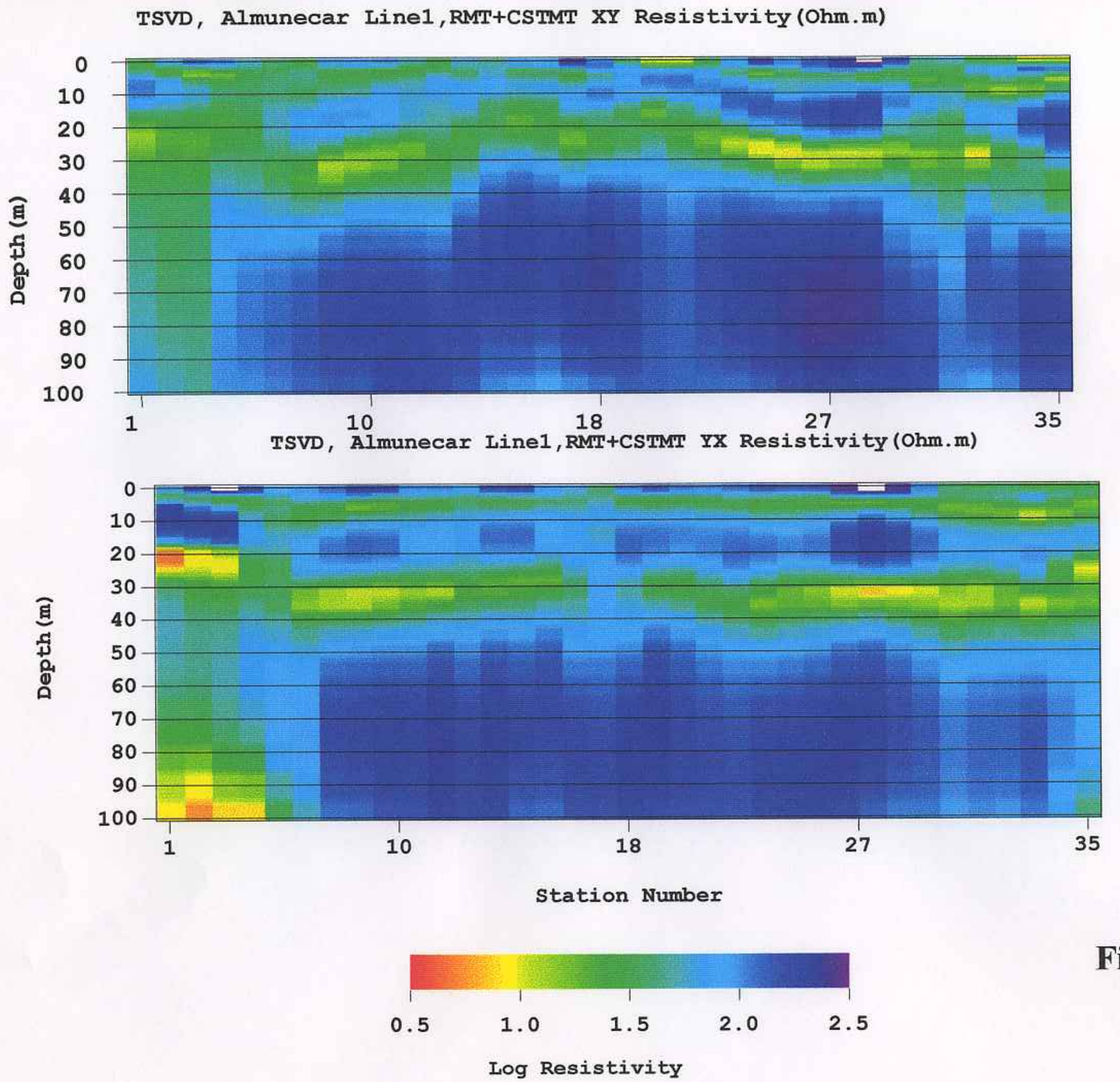

TSVD, Almunecar Line1,RMT+CSTMT XY Resistivity(Ohm.m)
Depth(m)
0
10
20
30
40
50
60
70
80
90
100
1
10
18
27
35
TSVD, Almunecar Line1,RMT+CSTMT YX Resistivity(Ohm.m)
Depth(m)
0
10
20
30
40
50
60
70
80
90
100
1
10
18
27
35
Station Number
0.5
1.0
1.5
2.0
2.5
Log Resistivity

Figure 1-7

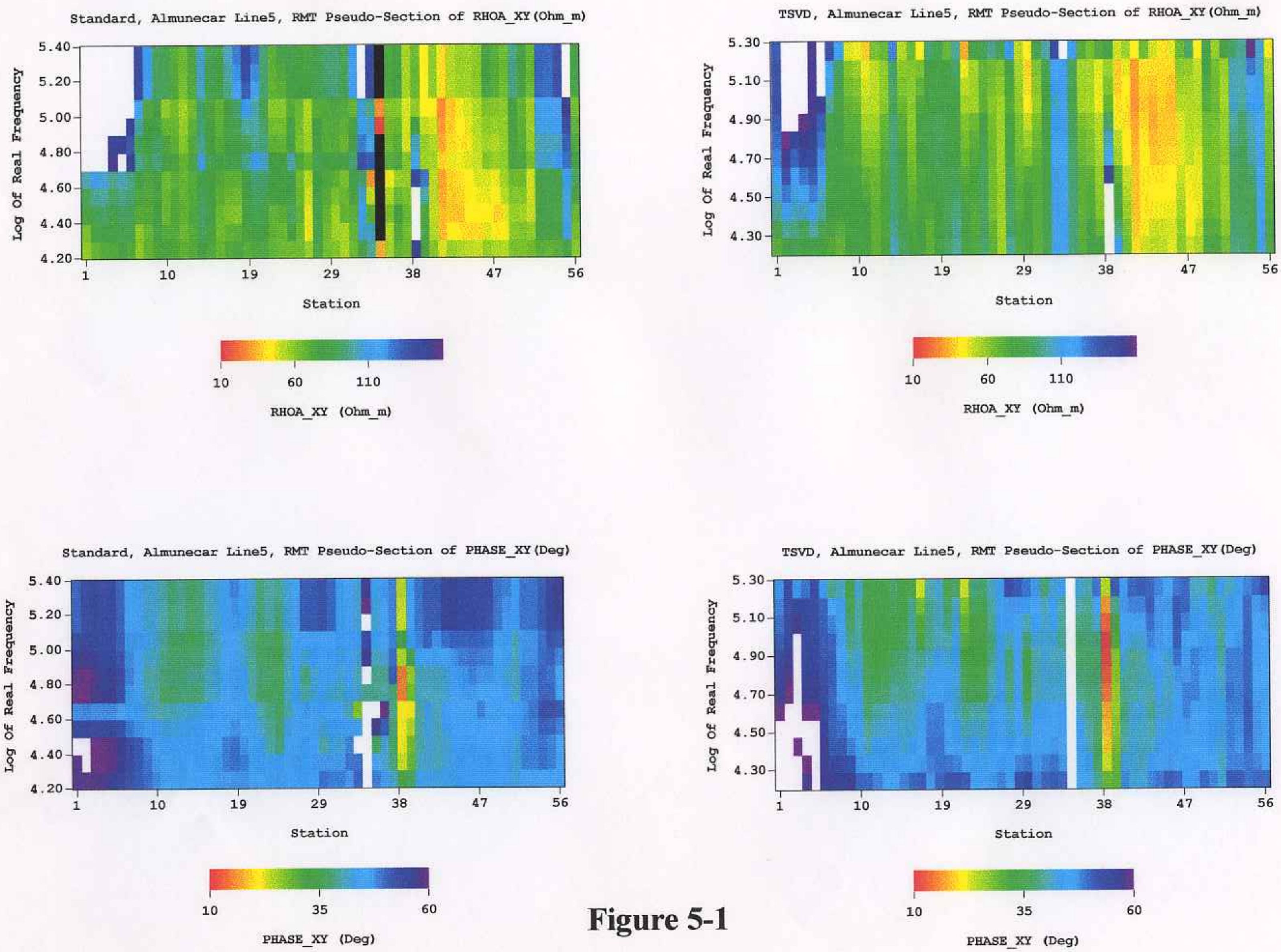

Standard, Almunecar Line5, RMT Pseudo-Section of RHOA_XY(Ohm_m)
Log Of Real Frequency
5.40
5.20
5.00
4.80
4.60
4.40
4.20
1
10
19
29
38
47
56
Station
10
60
110
RHOA_XY (Ohm_m)
TSVD, Almunecar Line5, RMT Pseudo-Section of RHOA_XY(Ohm_m)
Log Of Real Frequency
5.30
5.10
4.90
4.70
4.50
4.30
1
10
19
29
38
47
56
Station
10
60
110
RHOA_XY (Ohm_m)
Standard, Almunecar Line5, RMT Pseudo-Section of PHASE_XY(Deg)
Log Of Real Frequency
5.40
5.20
5.00
4.80
4.60
4.40
4.20
1
10
19
29
38
47
56
Station
10
35
60
PHASE_XY (Deg)
TSVD, Almunecar Line5, RMT Pseudo-Section of PHASE_XY(Deg)
Log Of Real Frequency
5.30
5.10
4.90
4.70
4.50
4.30
1
10
19
29
38
47
56
Station
10
35
60
PHASE_XY (Deg)

Figure 5-1

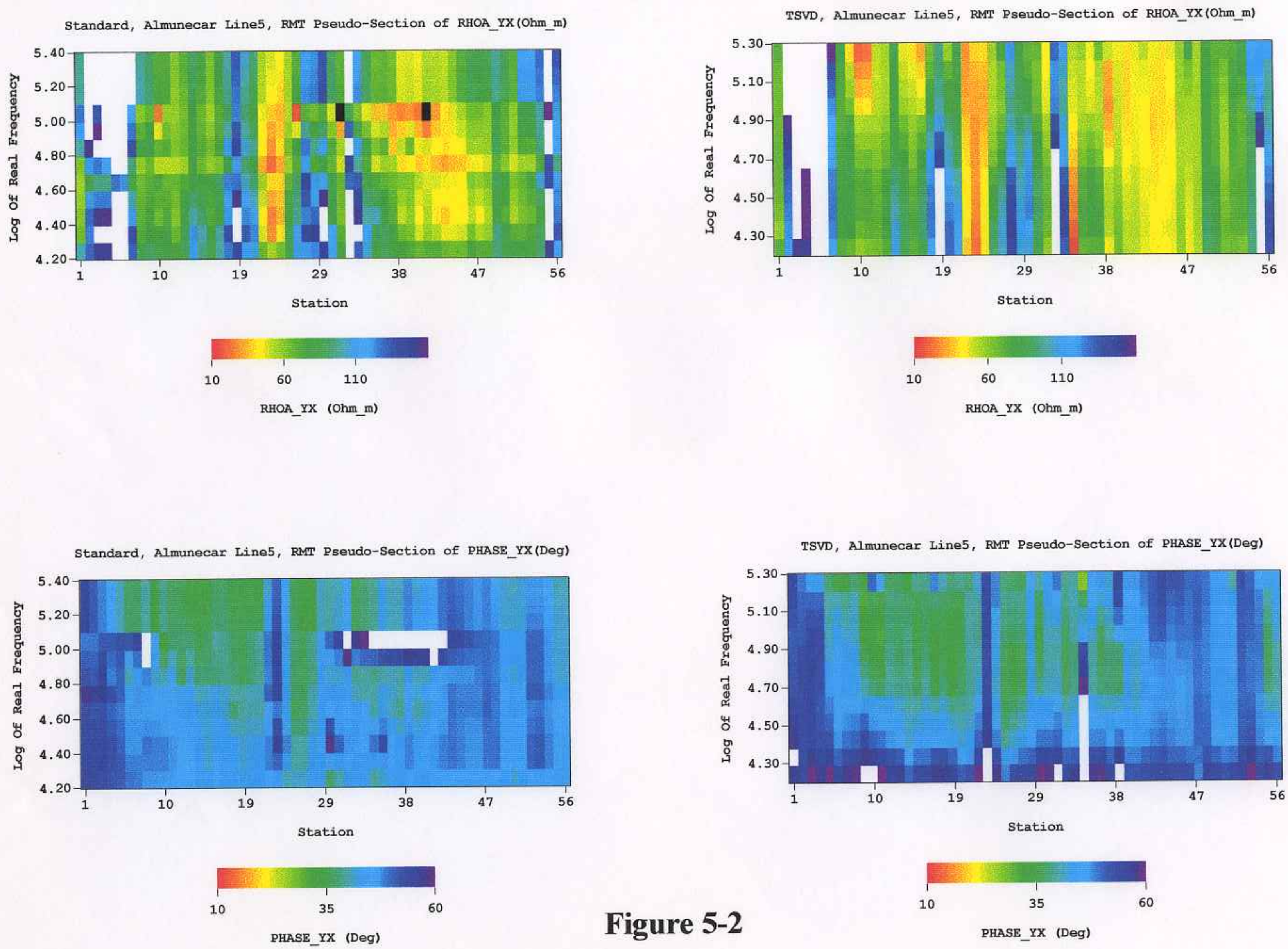

Standard, Almunecar Line5, RMT Pseudo-Section of RHOA_YX(Ohm_m)
Log Of Real Frequency
5.40
5.20
5.00
4.80
4.60
4.40
4.20
1
10
19
29
38
47
56
Station
10
60
110
RHOA_YX (Ohm_m)
TSVD, Almunecar Line5, RMT Pseudo-Section of RHOA_YX(Ohm_m)
Log Of Real Frequency
5.30
5.10
4.90
4.70
4.50
4.30
1
10
19
29
38
47
56
Station
10
60
110
RHOA_YX (Ohm_m)
Standard, Almunecar Line5, RMT Pseudo-Section of PHASE_YX(Deg)
Log Of Real Frequency
5.40
5.20
5.00
4.80
4.60
4.40
4.20
1
10
19
29
38
47
56
Station
10
35
60
PHASE_YX (Deg)
TSVD, Almunecar Line5, RMT Pseudo-Section of PHASE_YX(Deg)
Log Of Real Frequency
5.30
5.10
4.90
4.70
4.50
4.30
1
10
19
29
38
47
56
Station
10
35
60
PHASE_YX (Deg)

Figure 5-2

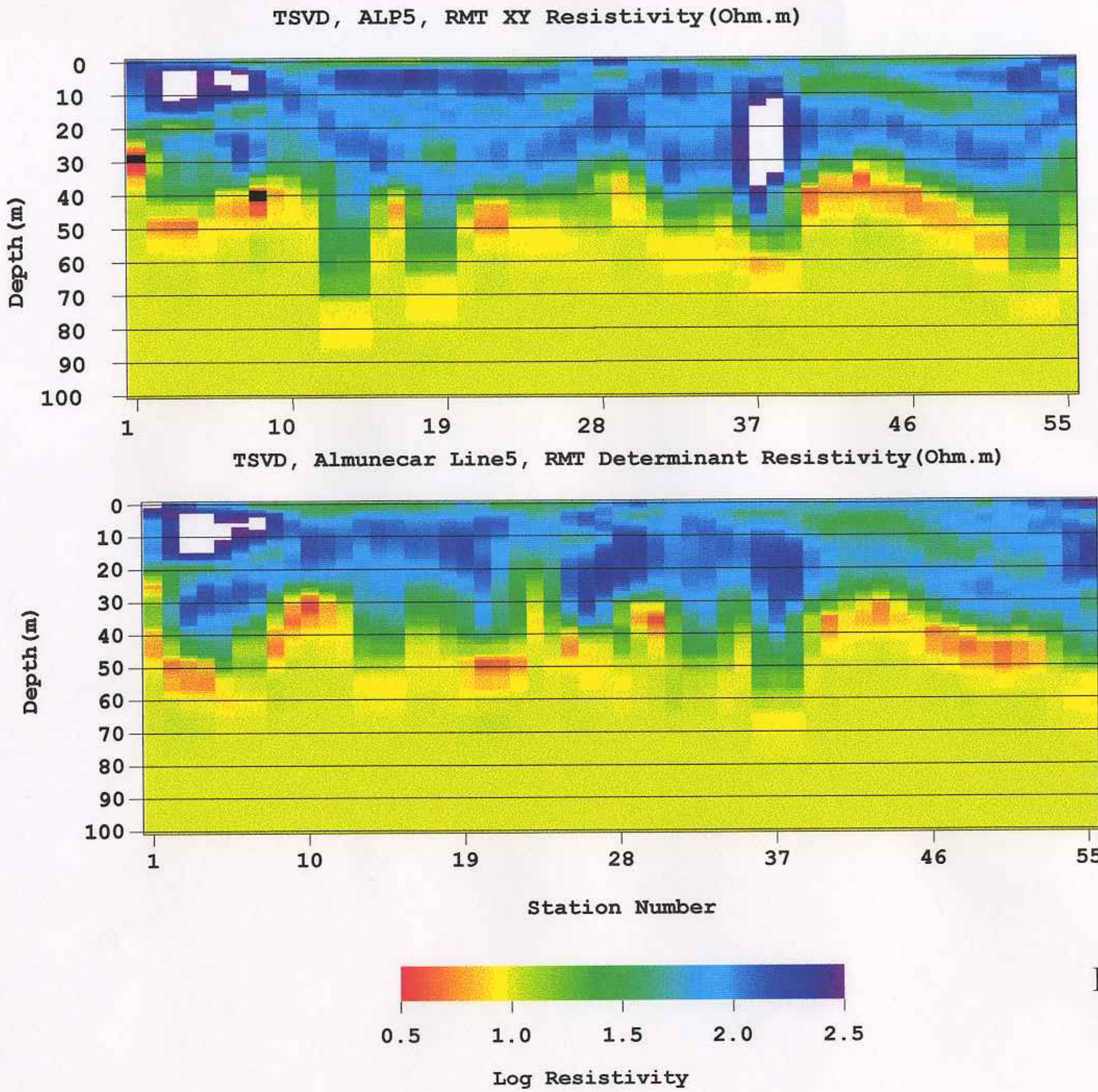

TSVD, ALP5, RMT XY Resistivity(Ohm.m)
Depth (m)
0
10
20
30
40
50
60
70
80
90
100
1
10
19
28
37
46
55
TSVD, Almunecar Line5, RMT Determinant Resistivity(Ohm.m)
Depth (m)
0
10
20
30
40
50
60
70
80
90
100
1
10
19
28
37
46
55
Station Number
0.5
1.0
1.5
2.0
2.5
Log Resistivity

Figure 5-3

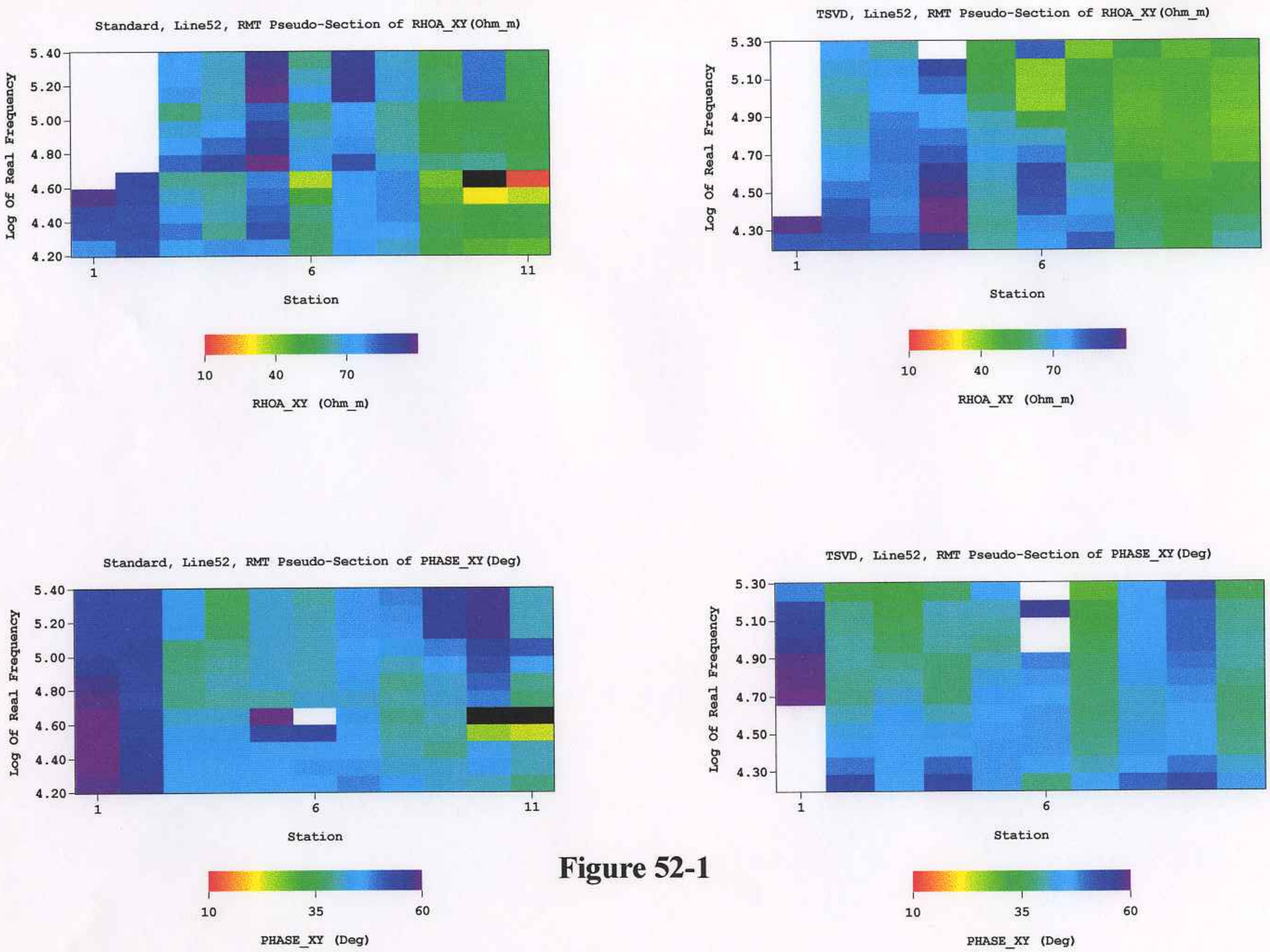

Standard, Line52, RMT Pseudo-Section of RHOA_XY (Ohm_m)
Log Of Real Frequency
5.40
5.20
5.00
4.80
4.60
4.40
4.20
1
6
11
Station
10
40
70
RHOA_XY (Ohm_m)
TSVD, Line52, RMT Pseudo-Section of RHOA_XY (Ohm_m)
Log Of Real Frequency
5.30
5.10
4.90
4.70
4.50
4.30
1
6
Station
10
40
70
RHOA_XY (Ohm_m)
Standard, Line52, RMT Pseudo-Section of PHASE_XY (Deg)
Log Of Real Frequency
5.40
5.20
5.00
4.80
4.60
4.40
4.20
1
6
11
Station
10
35
60
PHASE_XY (Deg)
TSVD, Line52, RMT Pseudo-Section of PHASE_XY (Deg)
Log Of Real Frequency
5.30
5.10
4.90
4.70
4.50
4.30
1
6
Station
10
35
60
PHASE_XY (Deg)

Figure 52-1

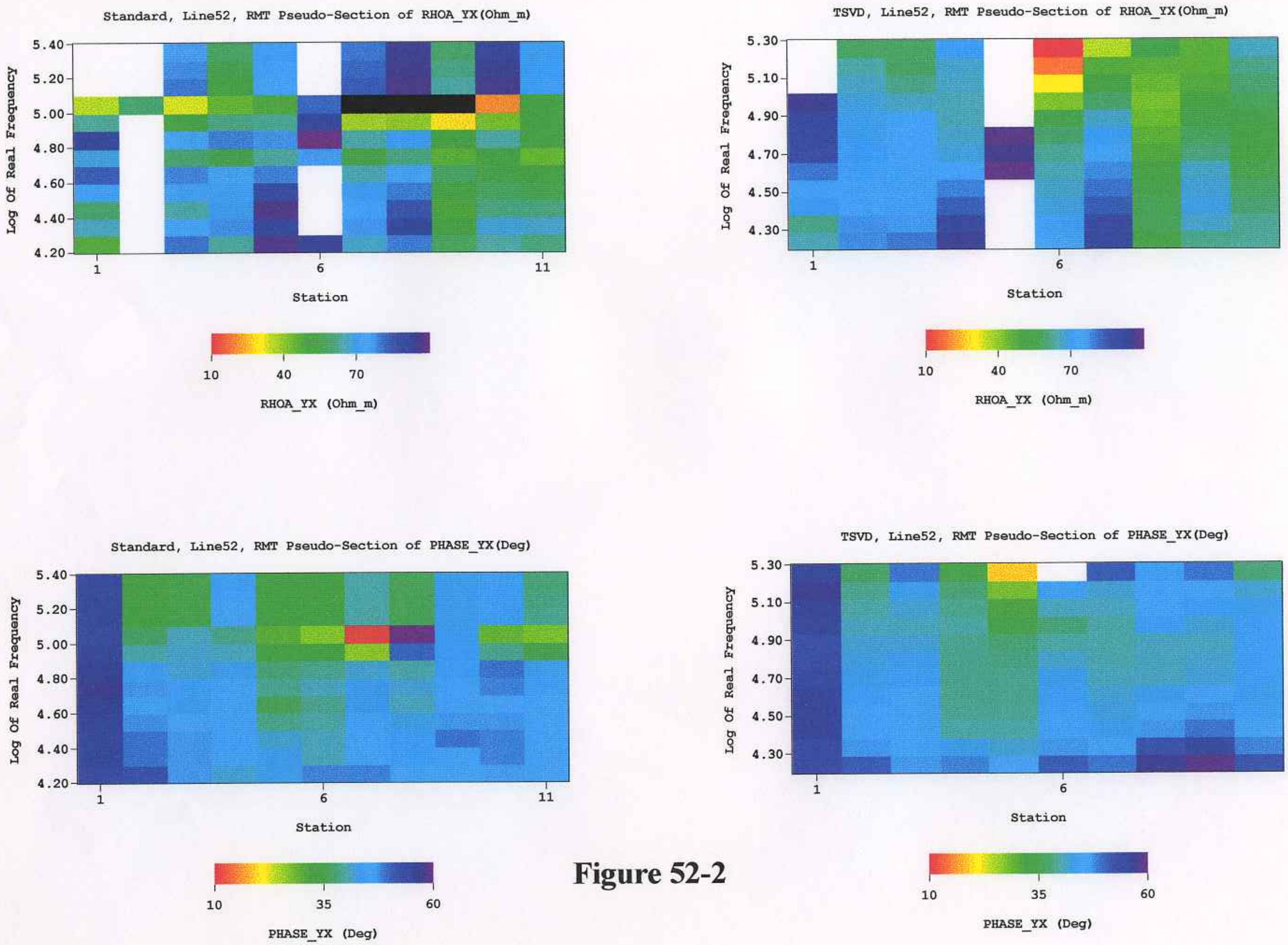
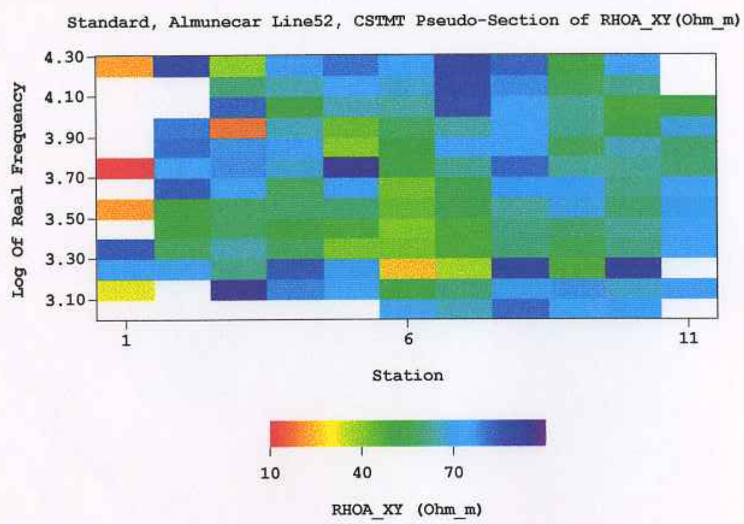
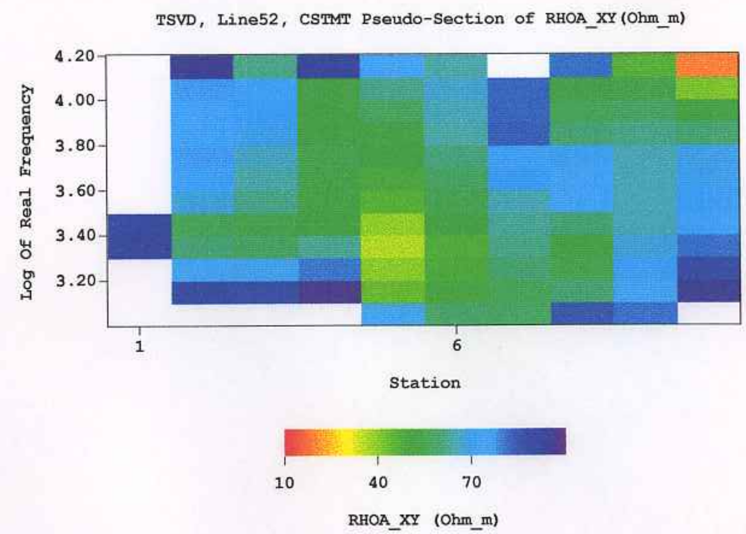
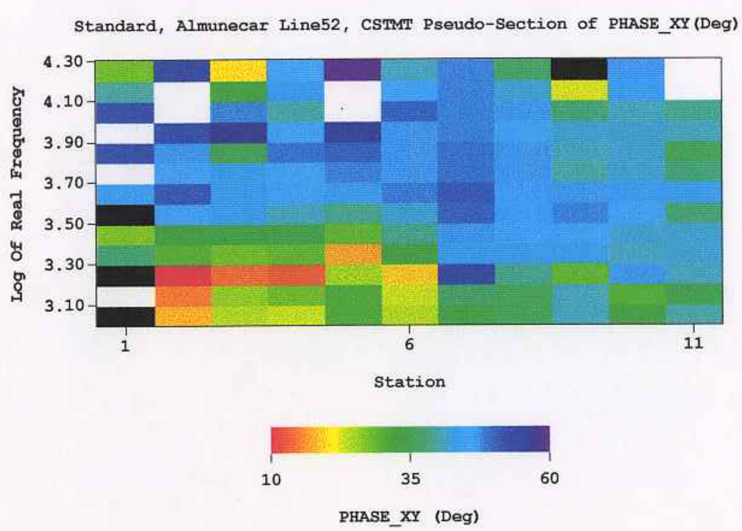

Standard, Line52, RMT Pseudo-Section of RHOA_YX(Ohm_m)
Log Of Real Frequency
5.40
5.20
5.00
4.80
4.60
4.40
4.20
1
6
11
Station
10
40
70
RHOA_YX (Ohm_m)
TSVD, Line52, RMT Pseudo-Section of RHOA_YX(Ohm_m)
Log Of Real Frequency
5.30
5.10
4.90
4.70
4.50
4.30
1
6
Station
10
40
70
RHOA_YX (Ohm_m)
Standard, Line52, RMT Pseudo-Section of PHASE_YX(Deg)
Log Of Real Frequency
5.40
5.20
5.00
4.80
4.60
4.40
4.20
1
6
11
Station
10
35
60
PHASE_YX (Deg)
TSVD, Line52, RMT Pseudo-Section of PHASE_YX(Deg)
Log Of Real Frequency
5.30
5.10
4.90
4.70
4.50
4.30
1
6
Station
10
35
60
PHASE_YX (Deg)

Figure 52-2


Standard, Almunecar Line52, CSTMT Pseudo-Section of RHOA_XY(Ohm_m)
Log Of Real Frequency
4.30
4.10
3.90
3.70
3.50
3.30
3.10
1
6
11
Station
10
40
70
RHOA_XY (Ohm_m)


TSVD, Line52, CSTMT Pseudo-Section of RHOA_XY(Ohm_m)
Log Of Real Frequency
4.20
4.00
3.80
3.60
3.40
3.20
1
6
Station
10
40
70
RHOA_XY (Ohm_m)


Standard, Almunecar Line52, CSTMT Pseudo-Section of PHASE_XY(Deg)
Log Of Real Frequency
4.30
4.10
3.90
3.70
3.50
3.30
3.10
1
6
11
Station
10
35
60
PHASE_XY (Deg)

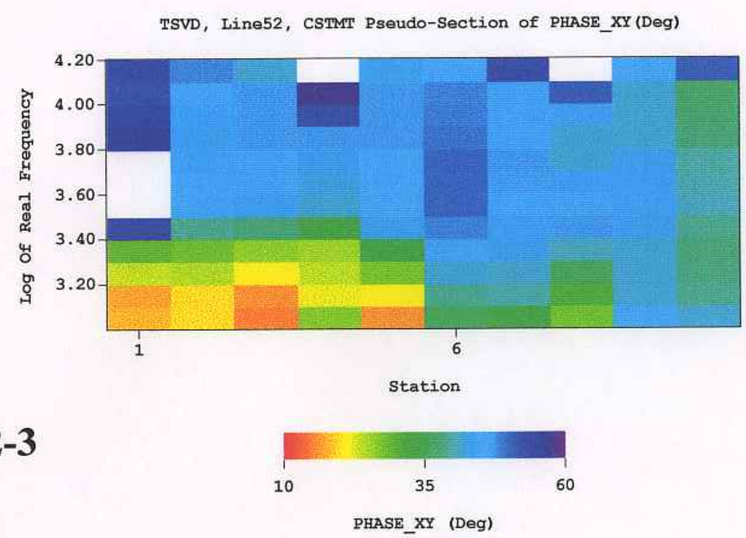
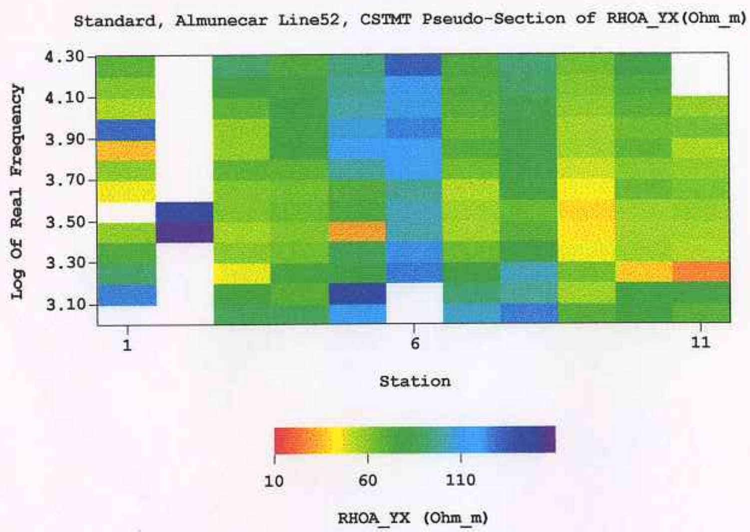
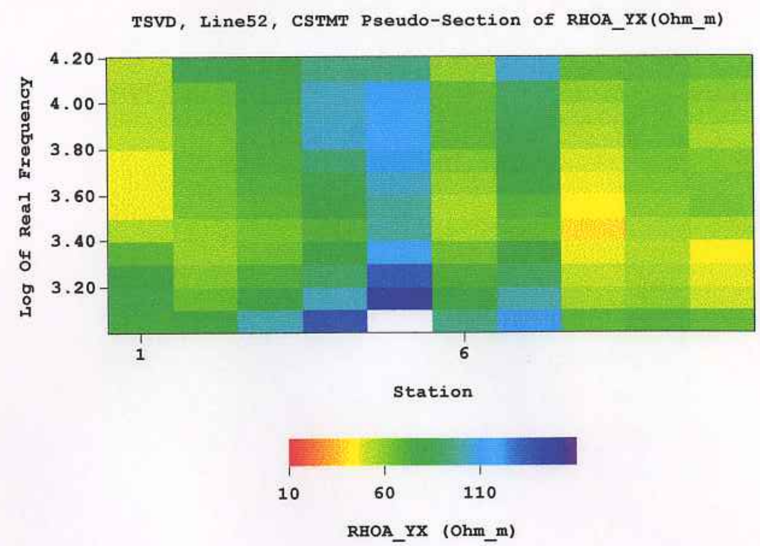
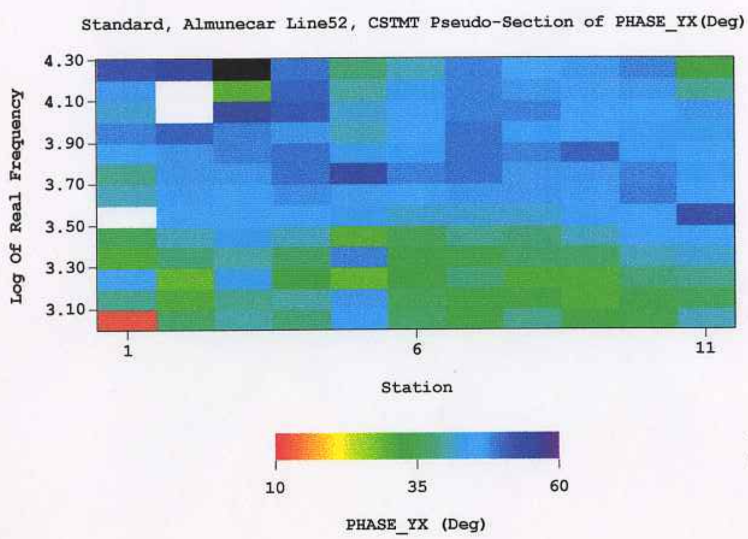

TSVD, Line52, CSTMT Pseudo-Section of PHASE_XY(Deg)
Log Of Real Frequency
4.20
4.00
3.80
3.60
3.40
3.20
1
6
Station
10
35
60
PHASE_XY (Deg)

Figure 52-3


Standard, Almunecar Line52, CSTMT Pseudo-Section of RHOA_YX(Ohm_m)
Log Of Real Frequency
4.30
4.10
3.90
3.70
3.50
3.30
3.10
1
6
11
Station
10
60
110
RHOA_YX (Ohm_m)


TSVD, Line52, CSTMT Pseudo-Section of RHOA_YX(Ohm_m)
Log Of Real Frequency
4.20
4.00
3.80
3.60
3.40
3.20
1
6
Station
10
60
110
RHOA_YX (Ohm_m)


Standard, Almunecar Line52, CSTMT Pseudo-Section of PHASE_YX(Deg)
Log Of Real Frequency
4.30
4.10
3.90
3.70
3.50
3.30
3.10
1
6
11
Station
10
35
60
PHASE_YX (Deg)

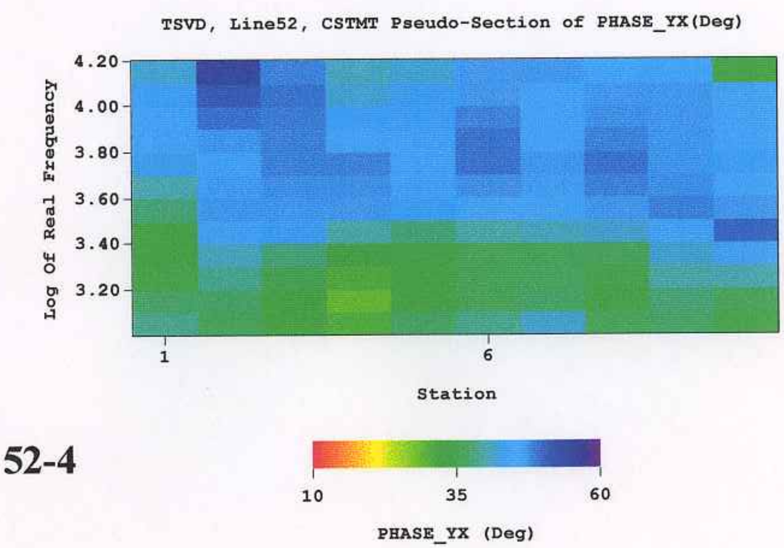

TSVD, Line52, CSTMT Pseudo-Section of PHASE_YX(Deg)
Log Of Real Frequency
4.20
4.00
3.80
3.60
3.40
3.20
1
6
Station
10
35
60
PHASE_YX (Deg)

Figure 52-4

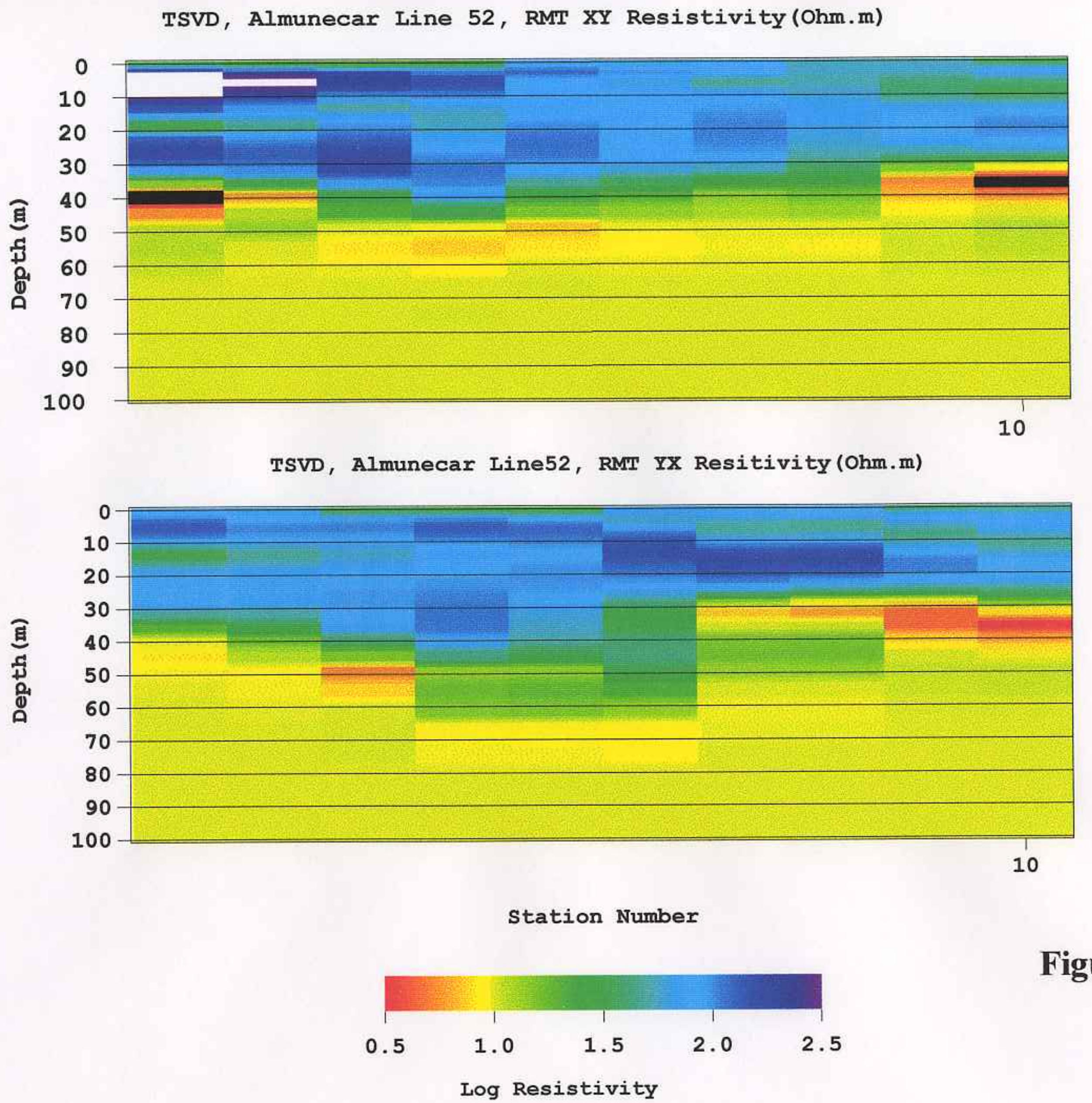

TSVD, Almunecar Line 52, RMT XY Resistivity(Ohm.m)
Depth (m)
0
10
20
30
40
50
60
70
80
90
100
10
TSVD, Almunecar Line52, RMT YX Resitivity(Ohm.m)
Depth (m)
0
10
20
30
40
50
60
70
80
90
100
10
Station Number
0.5
1.0
1.5
2.0
2.5
Log Resistivity

Figure 52-5

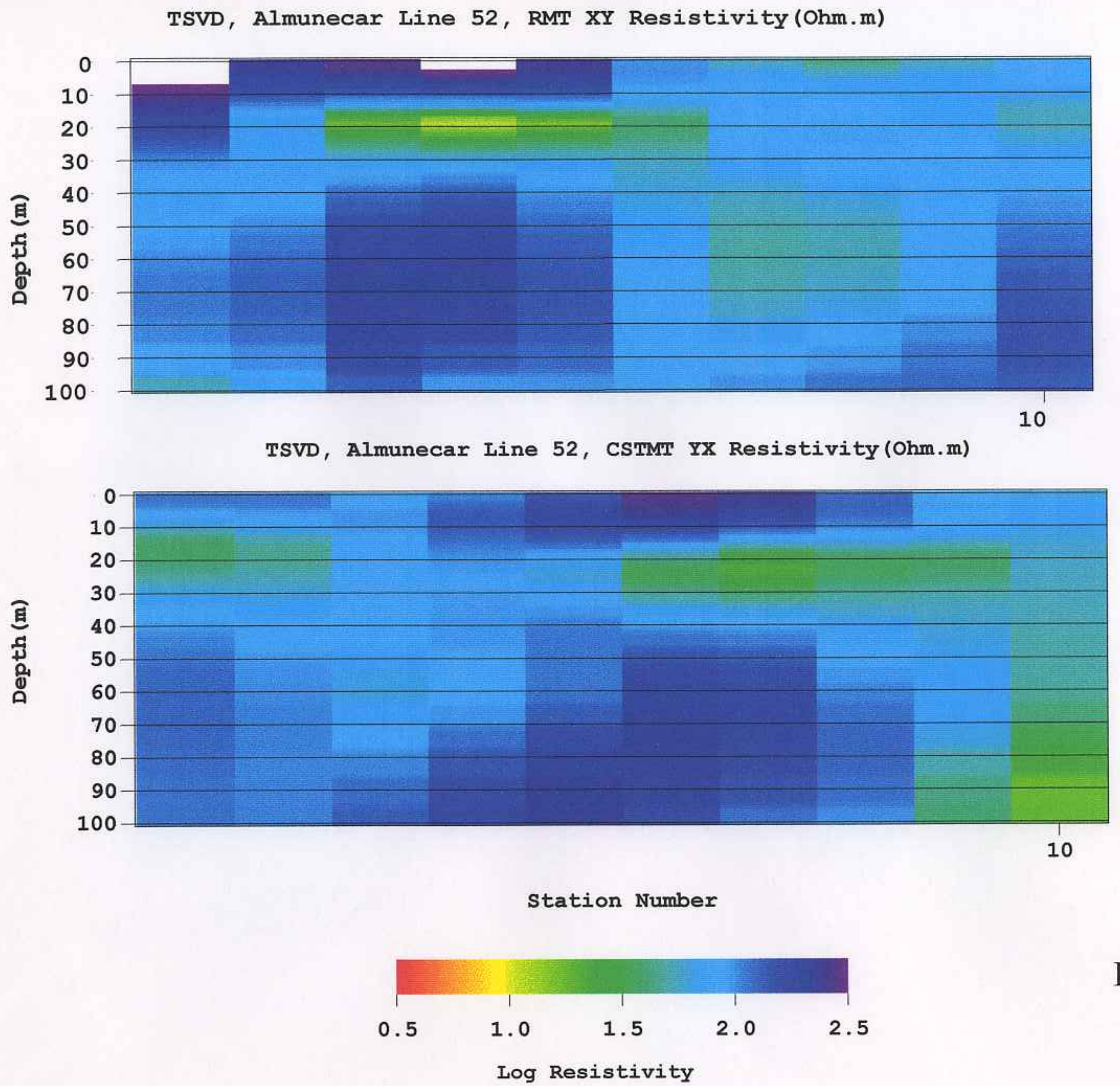

TSVD, Almunecar Line 52, RMT XY Resistivity(Ohm.m)
Depth (m)
0
10
20
30
40
50
60
70
80
90
100
10
TSVD, Almunecar Line 52, CSTMT YX Resistivity(Ohm.m)
Depth (m)
0
10
20
30
40
50
60
70
80
90
100
10
Station Number
0.5
1.0
1.5
2.0
2.5
Log Resistivity

Figure 52-6

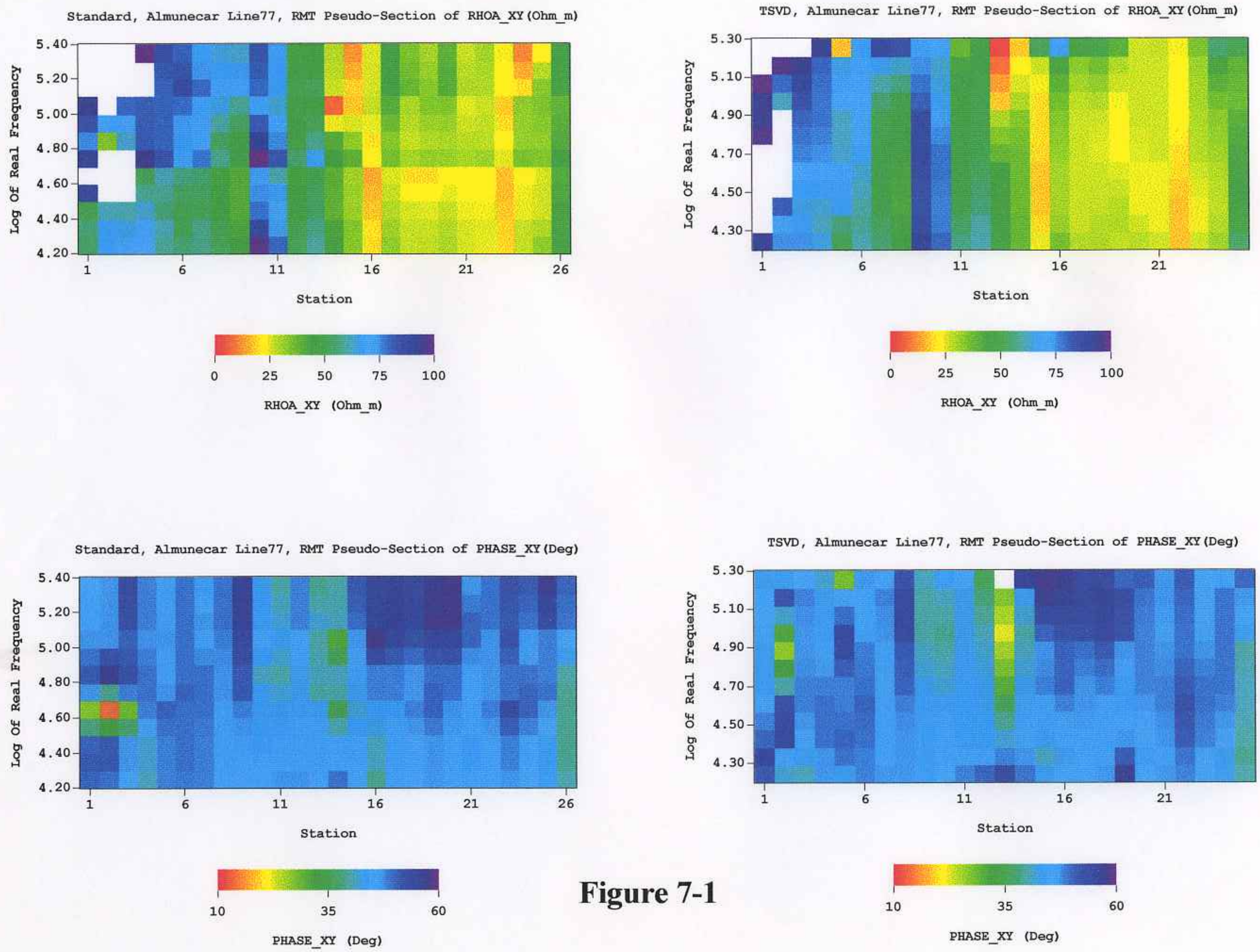
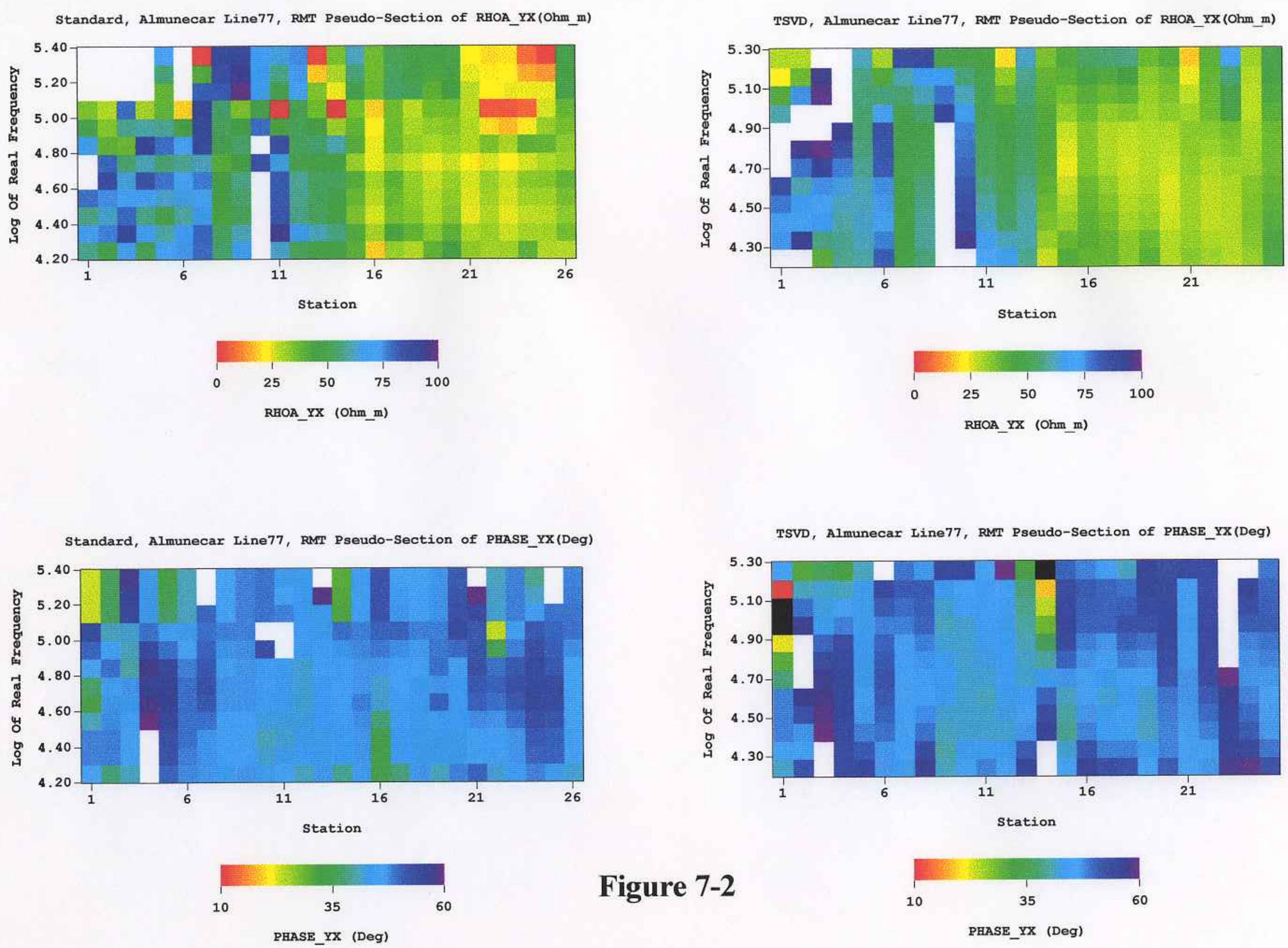

Standard, Almunecar Line77, RMT Pseudo-Section of RHOA_XY(Ohm_m)
Log Of Real Frequency
5.40
5.20
5.00
4.80
4.60
4.40
4.20
1
6
11
16
21
26
Station
0
25
50
75
100
RHOA_XY (Ohm_m)
TSVD, Almunecar Line77, RMT Pseudo-Section of RHOA_XY(Ohm_m)
Log Of Real Frequency
5.30
5.10
4.90
4.70
4.50
4.30
1
6
11
16
21
Station
0
25
50
75
100
RHOA_XY (Ohm_m)
Standard, Almunecar Line77, RMT Pseudo-Section of PHASE_XY(Deg)
Log Of Real Frequency
5.40
5.20
5.00
4.80
4.60
4.40
4.20
1
6
11
16
21
26
Station
10
35
60
PHASE_XY (Deg)
TSVD, Almunecar Line77, RMT Pseudo-Section of PHASE_XY(Deg)
Log Of Real Frequency
5.30
5.10
4.90
4.70
4.50
4.30
1
6
11
16
21
Station
10
35
60
PHASE_XY (Deg)

Figure 7-1



Standard, Almunecar Line77, RMT Pseudo-Section of RHOA_YX(Ohm_m)
Log Of Real Frequency
5.40
5.20
5.00
4.80
4.60
4.40
4.20
1
6
11
16
21
26
Station
0
25
50
75
100
RHOA_YX (Ohm_m)
TSVD, Almunecar Line77, RMT Pseudo-Section of RHOA_YX(Ohm_m)
Log Of Real Frequency
5.30
5.10
4.90
4.70
4.50
4.30
1
6
11
16
21
Station
0
25
50
75
100
RHOA_YX (Ohm_m)
Standard, Almunecar Line77, RMT Pseudo-Section of PHASE_YX(Deg)
Log Of Real Frequency
5.40
5.20
5.00
4.80
4.60
4.40
4.20
1
6
11
16
21
26
Station
10
35
60
PHASE_YX (Deg)
TSVD, Almunecar Line77, RMT Pseudo-Section of PHASE_YX(Deg)
Log Of Real Frequency
5.30
5.10
4.90
4.70
4.50
4.30
1
6
11
16
21
Station
10
35
60
PHASE_YX (Deg)

Figure 7-2

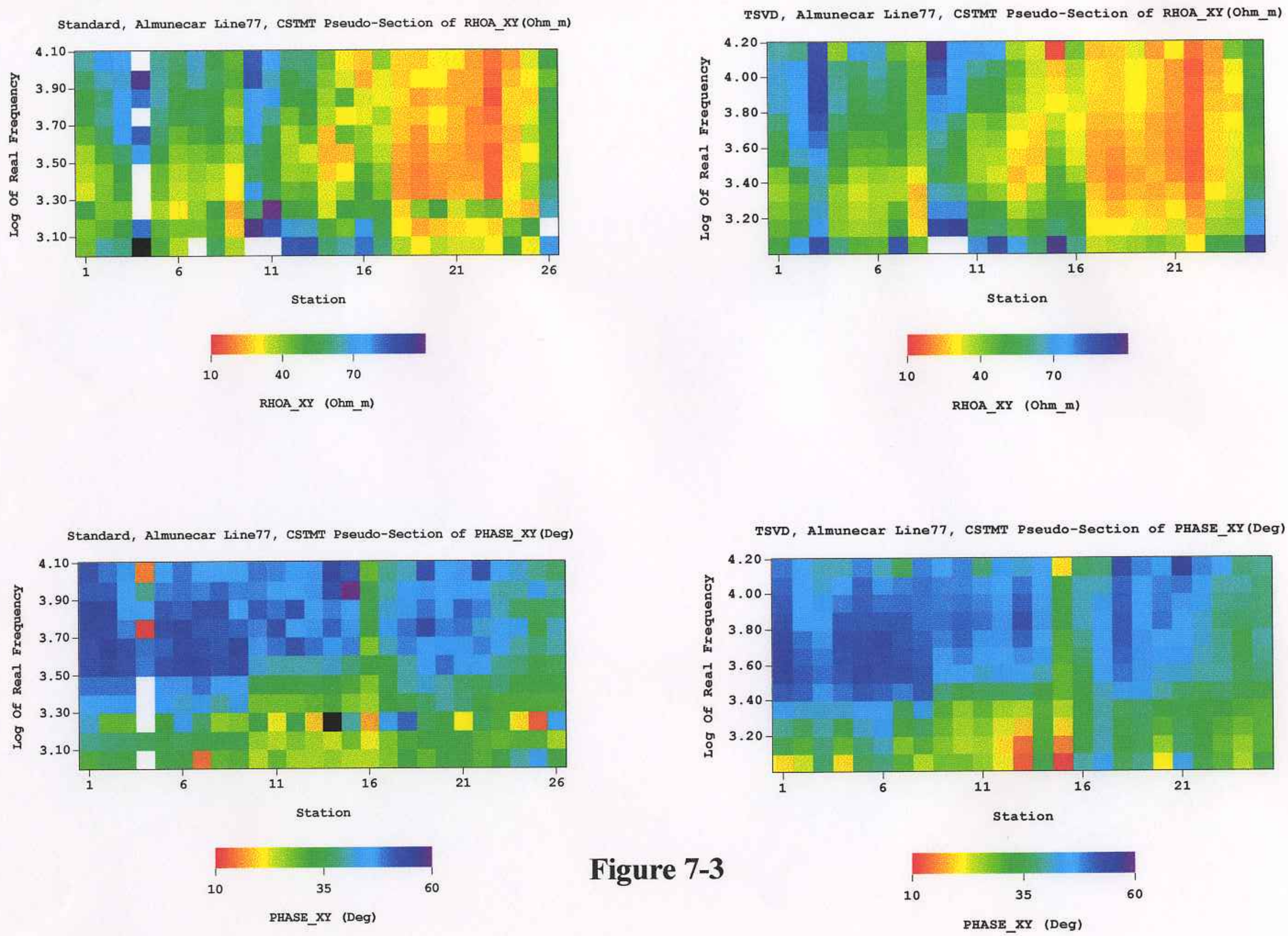

Standard, Almunecar Line77, CSTMT Pseudo-Section of RHOA_XY(Ohm_m)
Log Of Real Frequency
4.10
3.90
3.70
3.50
3.30
3.10
1
6
11
16
21
26
Station
10
40
70
RHOA_XY (Ohm_m)
TSVD, Almunecar Line77, CSTMT Pseudo-Section of RHOA_XY(Ohm_m)
Log Of Real Frequency
4.20
4.00
3.80
3.60
3.40
3.20
1
6
11
16
21
Station
10
40
70
RHOA_XY (Ohm_m)
Standard, Almunecar Line77, CSTMT Pseudo-Section of PHASE_XY(Deg)
Log Of Real Frequency
4.10
3.90
3.70
3.50
3.30
3.10
1
6
11
16
21
26
Station
10
35
60
PHASE_XY (Deg)
TSVD, Almunecar Line77, CSTMT Pseudo-Section of PHASE_XY(Deg)
Log Of Real Frequency
4.20
4.00
3.80
3.60
3.40
3.20
1
6
11
16
21
Station
10
35
60
PHASE_XY (Deg)

Figure 7-3

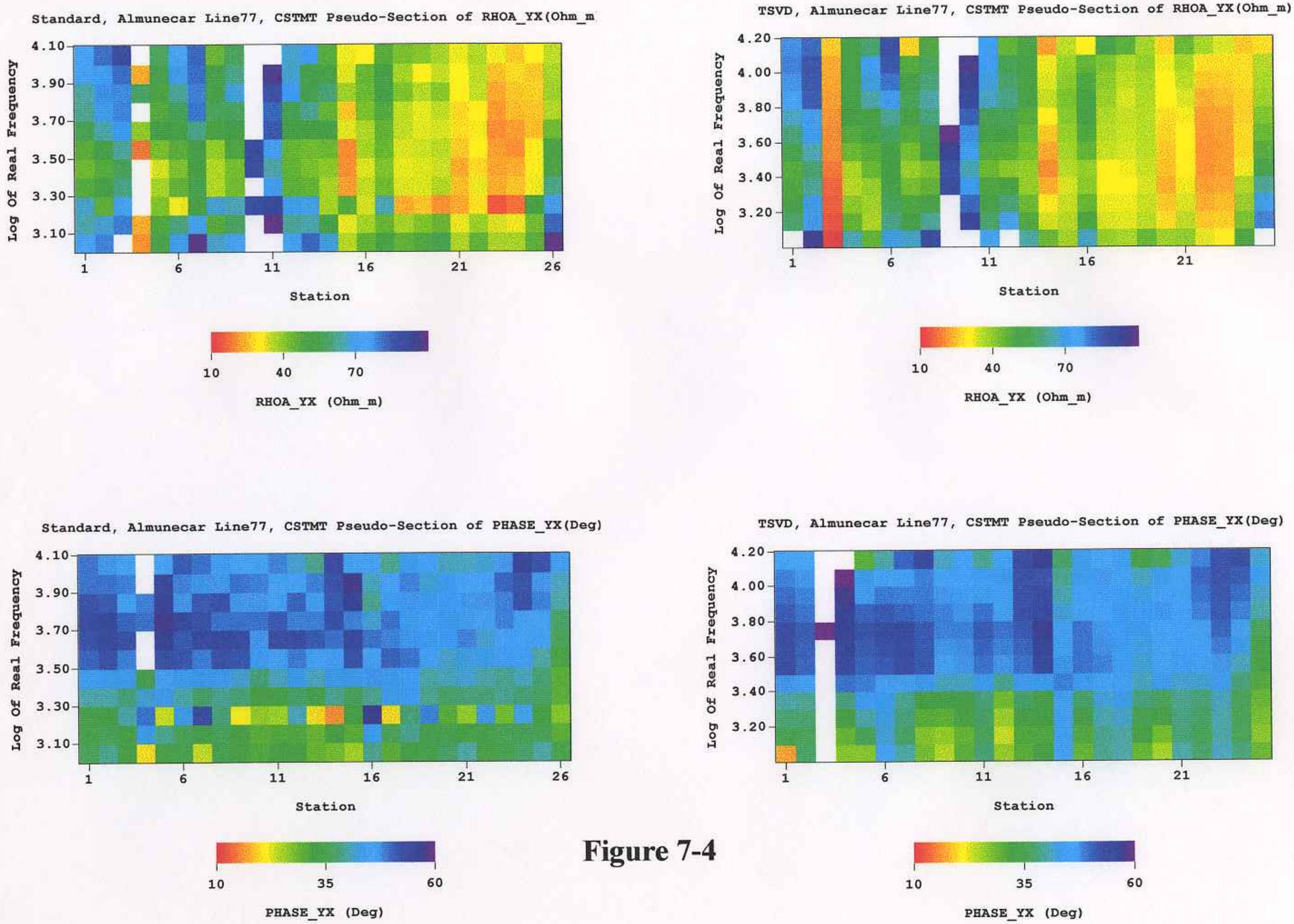

Standard, Almunecar Line77, CSTMT Pseudo-Section of RHOA_YX(Ohm_m
Log Of Real Frequency
4.10
3.90
3.70
3.50
3.30
3.10
1
6
11
16
21
26
Station
10
40
70
RHOA_YX (Ohm_m)
TSVD, Almunecar Line77, CSTMT Pseudo-Section of RHOA_YX(Ohm_m)
4.20
4.00
3.80
3.60
3.40
3.20
RHOA_YX (Ohm_m)
Standard, Almunecar Line77, CSTMT Pseudo-Section of PHASE_YX(Deg)
10
35
60
PHASE_YX (Deg)
TSVD, Almunecar Line77, CSTMT Pseudo-Section of PHASE_YX(Deg)
PHASE_YX (Deg)

Figure 7-4

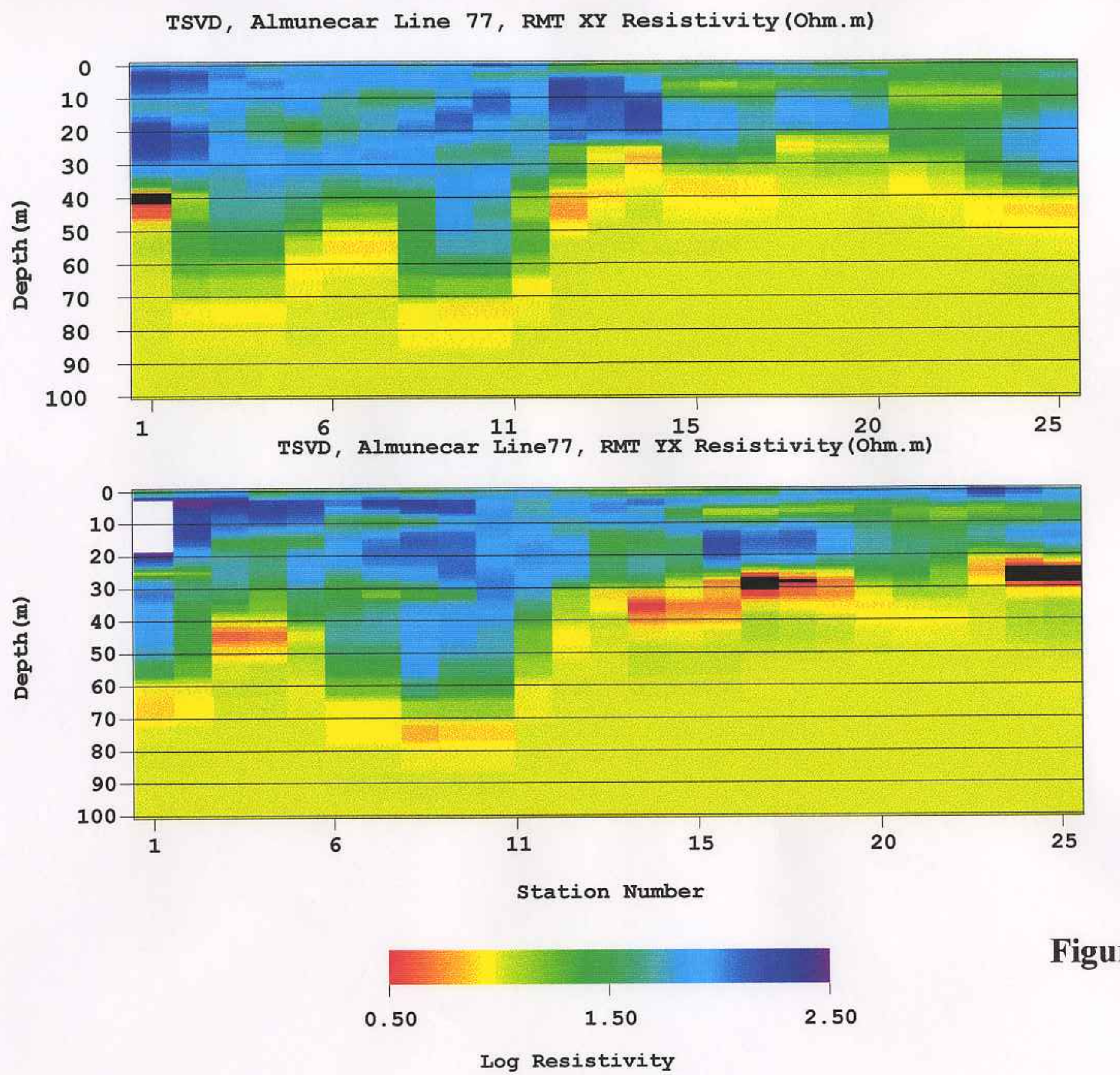

TSVD, Almunecar Line 77, RMT XY Resistivity(Ohm.m)
Depth (m)
0
10
20
30
40
50
60
70
80
90
100
1
6
11
15
20
25
TSVD, Almunecar Line77, RMT YX Resistivity(Ohm.m)
Depth (m)
Station Number
0.50
1.50
2.50
Log Resistivity

Figure 7-5

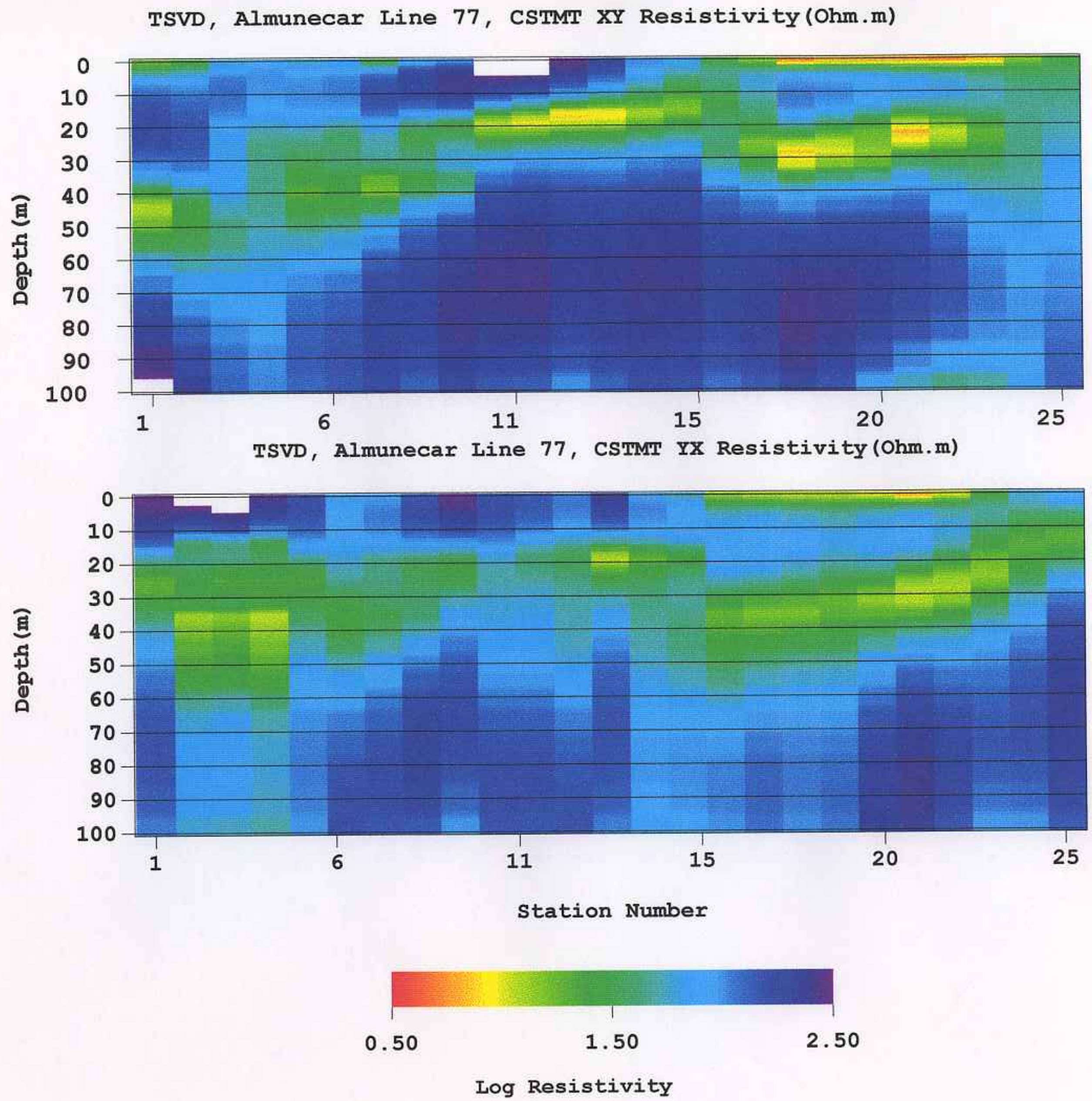

TSVD, Almunecar Line 77, CSTMT XY Resistivity(Ohm.m)
Depth (m)
0
10
20
30
40
50
60
70
80
90
100
1
6
11
15
20
25
TSVD, Almunecar Line 77, CSTMT YX Resistivity(Ohm.m)
Depth (m)
Station Number
0.50
1.50
2.50
Log Resistivity

Figure 7-6

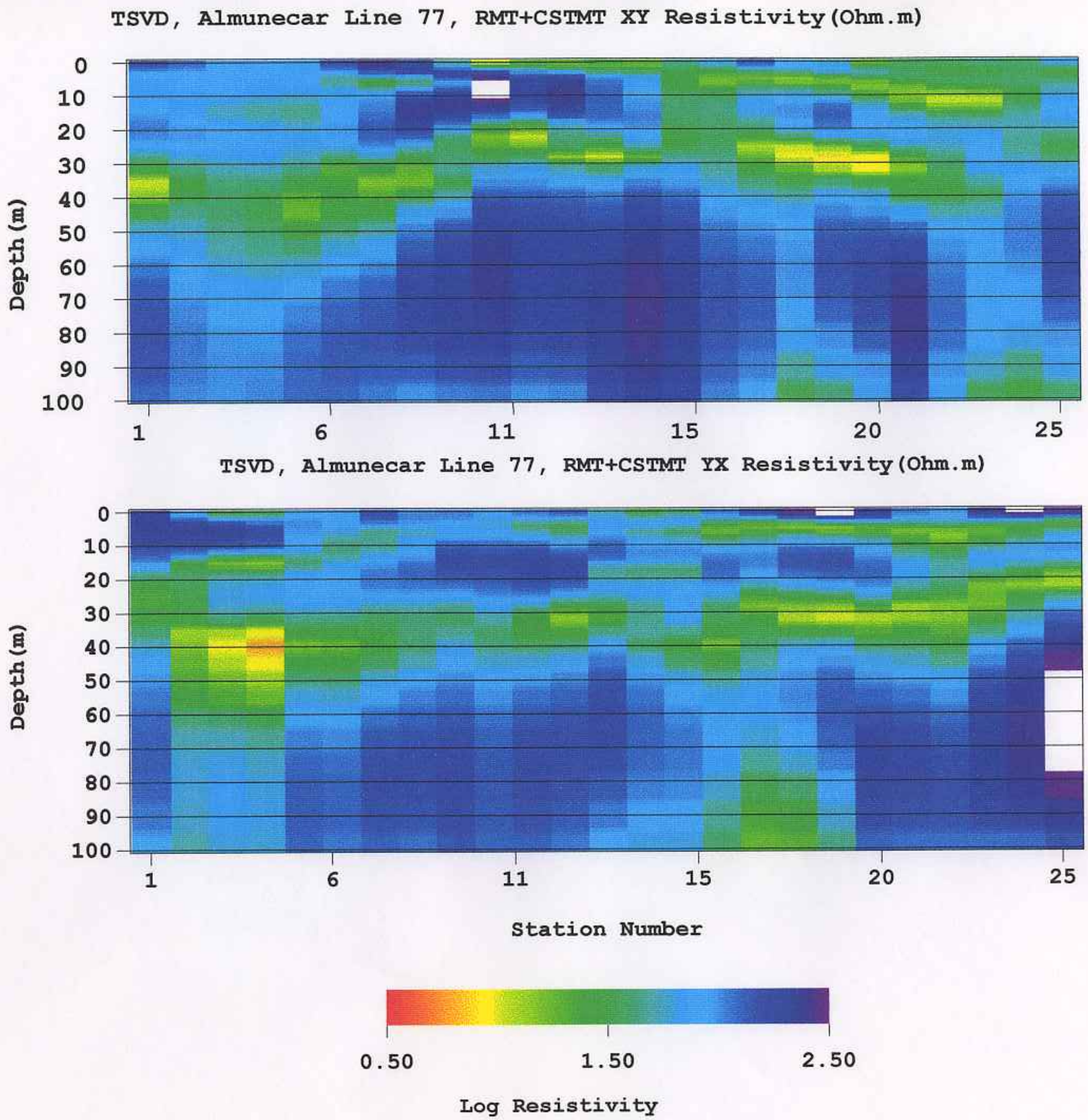

TSVD, Almunecar Line 77, RMT+CSTMT XY Resistivity(Ohm.m)
Depth (m)
0
10
20
30
40
50
60
70
80
90
100
1
6
11
15
20
25
TSVD, Almunecar Line 77, RMT+CSTMT YX Resistivity(Ohm.m)
Depth (m)
Station Number
0.50
1.50
2.50
Log Resistivity

Figure 7-7