Working Report 2006-69

Gefinex 400S (Sampo) EM-Soundings at Olkiluoto 2006

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August 2006

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GEFINEX 400S (SAMPO) EM-LUOTAUKSET OLKILUODOSSA 2006

TIIVISTELMÄ

Geologian tutkimuskeskus teki kesän 2006 alussa sähkömagneettisia taajuusluotauksia Gefinex 400S-laitteistolla (Sampo) Onkalon ympäristössä, Olkiluodon ydinvoimala-alueella. Mittauksessa toistettiin kahtena edellisenä vuonna samaan vuodenaikaan tehdyt luotaukset käyttäen hyväksi maastoon vuonna 2004 merkittyjä lähetin- ja vastaanotinpisteiden paikkoja.

Monitorointimittausten tavoitteena on lähinnä seurata mahdollisista pohjavesimuutoksista aiheutuvia maankamaran sähkönjohtavuuden muutoksia ONKALO:n ja loppusijoitustilojen alueella. Mittausverkko muodostuu kahdesta samansuuntaisesta toisistaan 200 m:n etäisyydellä sijaitsevasta 1400 m pitkästä rintamamittaus-profiilista, joissa pisteväli on 200 m. Profiilit on mitattu kolmella eri kelavälillä: 200, 500 ja 800 m. Kaikkiaan tehtiin 48 luotausta.

Luotaustuloksissa esiintyy runsaasti alueen lukuisten kaapelien ja sähkölinjojen aiheuttamia häiriöefektejä. Häiriöiden takia 8 pisteessä ei saatu mittaustulosta ja näistä muutamassa ei pystytty tekemään edes taustamittausta. Samassa pisteessä peräkkäin tehtyjen luotausten toistettavuus on hyvä. Parhaiten monitorointiin sopivat kuitenkin pisteet, joissa ei ole voimakkaita 3-D efektejä.

Vertaamalla uusia käyriä vuoden 2004 ja 2005 mittauksiin voidaan havaita pieniä muutoksia eräissä ARD (apparent resistivity-depth)-käyrissä.

Avainsanat: Elektromagneettiset taajuusluotaukset, Sampo, Olkiluoto, ONKALO, loppusijoitus, sähköisten johteiden monitorointi

GEFINEX 400S (SAMPO) EM-SOUNDINGS AT OLKILUOTO 2006

ABSTRACT

In the beginning of summer 2006 Geological Survey of Finland carried out electromagnetic frequency soundings with Gefinex 400S equipment (called also Sampo) at Onkalo situated in Olkiluoto nuclear power plant area. The same soundings sites were the first time measured and marked in 2004 and repeated in 2005. The aim of the measurements is to monitor the changes of groundwater conditions by the changes of the electric conductivity of the earth at ONKALO and repository area.

The measurements form two 1400 m long broadside profiles, which have 200 m mutual distance and 200 m station separation. The profiles have been measured using 200, 500, and 800 m coil separations. The total number of the soundings was 48 but at 8 stations the measurement did not succeed because of strong electromagnetic noise.

The numerous power lines and the cables of the area generate local 3-D effects on the sounding curves, but the repeatability of the results is good. However, most suitable for monitoring purposes are the sites without strong 3-D effects. Comparison of results 2004-2006 shows small differences at some sounding sites.

Key Words: Electromagnetig frequency soundings, Sampo, Olkiluoto, ONKALO, repository, monitoring of electric conductors

GEFINEX 400S (SAMPO) EM SOUNDINGS AT OLKILUOTO 2006

TIIVISTELMÄ

ABSTRACT

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GEFINEX 400S (SAMPO) EM SOUNDINGS AT OLKILUOTO 2006

1. FOREWORD

The work was done using electromagnetic frequency domain sounding system Gefinex 400S owned by GTK. The field team consisted of geophysicist Jukka Lehtimäki and assistants Jukka Piispa, Keijo Kontio and Terho Turunen. This report is prepared by Tarmo Jokinen and Jukka Lehtimäki

2. METHOD AND INTSRUMENTATION

GEFINEX 400S (known also as SAMPO) is a frequency domain wide band electromagnetic sounding system developed in cooperation by Outokumpu Elektroniikka and Geological Survey of Finland (GTK). The system has been used in general structural mapping, mineral exploration, groundwater studies, especially mapping of saline interfaces and in engineering site investigations and other environmental applications.

The transmitter is a horizontal current loop that creates a vertical magnetic dipole. The diameter of the loop varies according to the used transmitter - receiver (Tx - Rx) separation from 10 - 65 m. The receiver measures 3 perpendicular components of the total field. The relations Bz/Br, Bz/Bt and the phase differencies between the components are calculated. The system operates at 81 fixed frequencies within the band 2 - 20000 Hz. The maximum investigation depth is about the same as the distance between the Tx and the Rx, which can be selected from 50 to 1500 m.

There is a radio link between Tx and Rx and no cable connection is needed. The profiles can be measured using in-line or broad-side configuration. For data presentation the midpoint of Tx-Rx represents the measurement point, but the method is not reciprocal. Figure (1) shows the measurement configuration of the system.

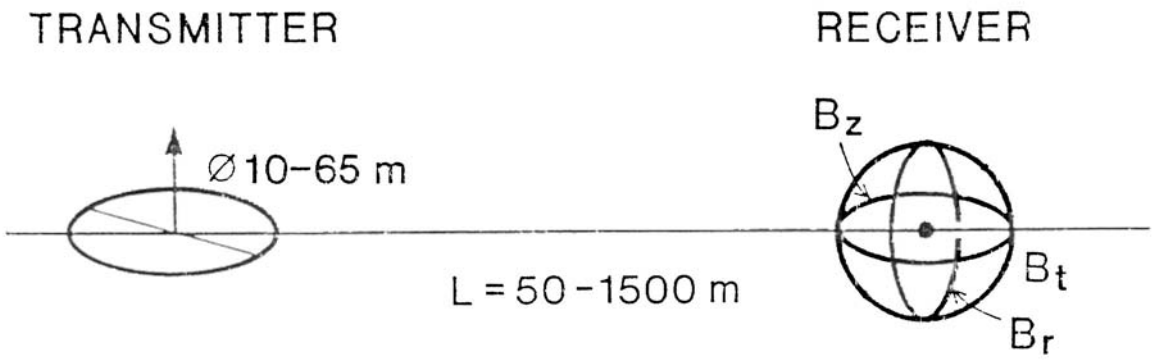

Figure 1. Measurement configuration of the SAMPO EM system.

SAMPO measurement program controls the quality of the data during the sounding. Every measured frequency is controlled separately. If the variation of the readings is higher than the value set by the operator, the instrument stacks more readings to get the good result. The readings are stored in the memory of receiver. It takes typically less than 10 minutes to measure the whole frequency band.

3. DATA PROCESSING

At field camp the results are downloaded to PC and a backup copy is done.

In the data processing the apparent resistivity-depth (ARD-) transformation is calculated. The ARD-transformation is calculated individually for every frequency by the measured ratio of the vertical and the radial magnetic fields (Bz/Br) and the coil separation. ARD-transformation is based on a horizontal two-layer model (Aittoniemi et all).The ratio Bz/Br depends on the conductivity structure of the earth and the geometry between transmitter and receiver coils.

In the interpretation it's supposed that the transmitter loop and the horizontal receiver loop are lying on the same plane. The effect of the geometry (tilt and height deviations) is removed mathematically from the ratio Bz/Br. The correction is based on the fact that at low frequencies the Br component is caused almost totally by the alignment errors between transmitter and receiver loops.

The ARD-transformation makes it easier to visually estimate the number and the depth of the layers for the inversion and to estimate the fit between the measured and the calculated theoretical data. The sounding curve is presented in a picture where the resistivities increase to the right on the horizontal axis and the depth increases downwards on the vertical axis (Fig. 2).

If the earth is a homogenous half space the points of the sounding curve form a vertical straight line. The position of the line on the resistivity axis shows the resistivity of the homogenous half space (Fig. 2, curve A). When the second layer of the model is more conductive than the topmost one the curve starts to turn to the left (to the more conductive direction) at the depth of the conductor. After getting through the conductors the sounding curve turns back to the vertical direction (Fig 2, curve B).

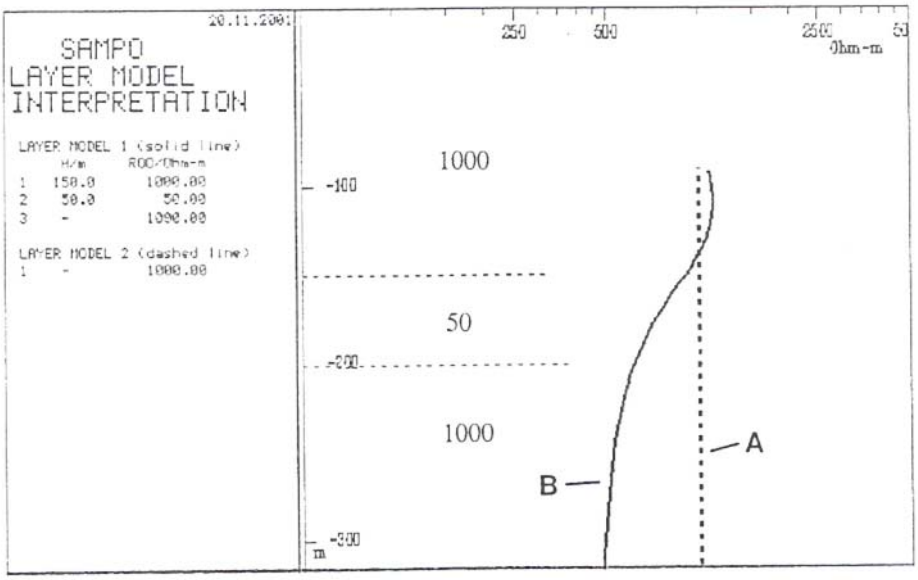

Figure 2. Sampo sounding curves.
Homogenious half space (A), conductive intermediate layer (B)

4. FIELD WORK

The field work was done during one week, from 29th May to 2nd June. The same LK coordinate system (Fig. 1-3) was used as in the 2004 and 2005 surveys. The Tx- and Rx-stations were marked by sticks already in 2004.

The coordinates of the common point of KKJ and LK systems are:

X=6791.352
Y=1526.200
L=10.000
K=50.000

The angle between X (north) and K is 35.166 degrees

The wooden Tx-marks are placed in the middle of the circular 20 m transmitter loop. With the 50 m x 50 m square loop the mark of the loop is in the middle of the side, that is situated on the L-line. So the midpoint of the loop is situated 25 m from the line. During the survey some lost marker sticks were replaced and marked with tape using Focus DGPS system.

The study consisted of two parallel 1400 m long broadside lines, which were measured using Tx/Rx distances 200 m, 500 m and 800 m. The Tx loop diameter for 200 m soundings was 20 m and 50 m x 50 m for 500 m and 800 m soundings. The station interval was 200 m.
All coil separations of the two adjacent broadside sounding points of lines K=50.400 and 50.600 were measured one after another. Tx and Rx moved along L-lines. In practice the fieldwork resembled in-line measurement using varying coil separations. The final broadside lines were later collected from the in-line data.

There are 5 soundings with exceptional Tx/Rx direction. Those soundings are not based on the LK-coordinate system (These soundings are marked with XY In appendices 2 and 3). The site of Rx has been determined with Garmin GPS 48 and the site of Tx with Focus DGPS.

In all 48 soundings were measured. Location coordinates are listed in appendices 1-3.
At 8 stations the measurement did not succeed (“No results” in the appendices note column).

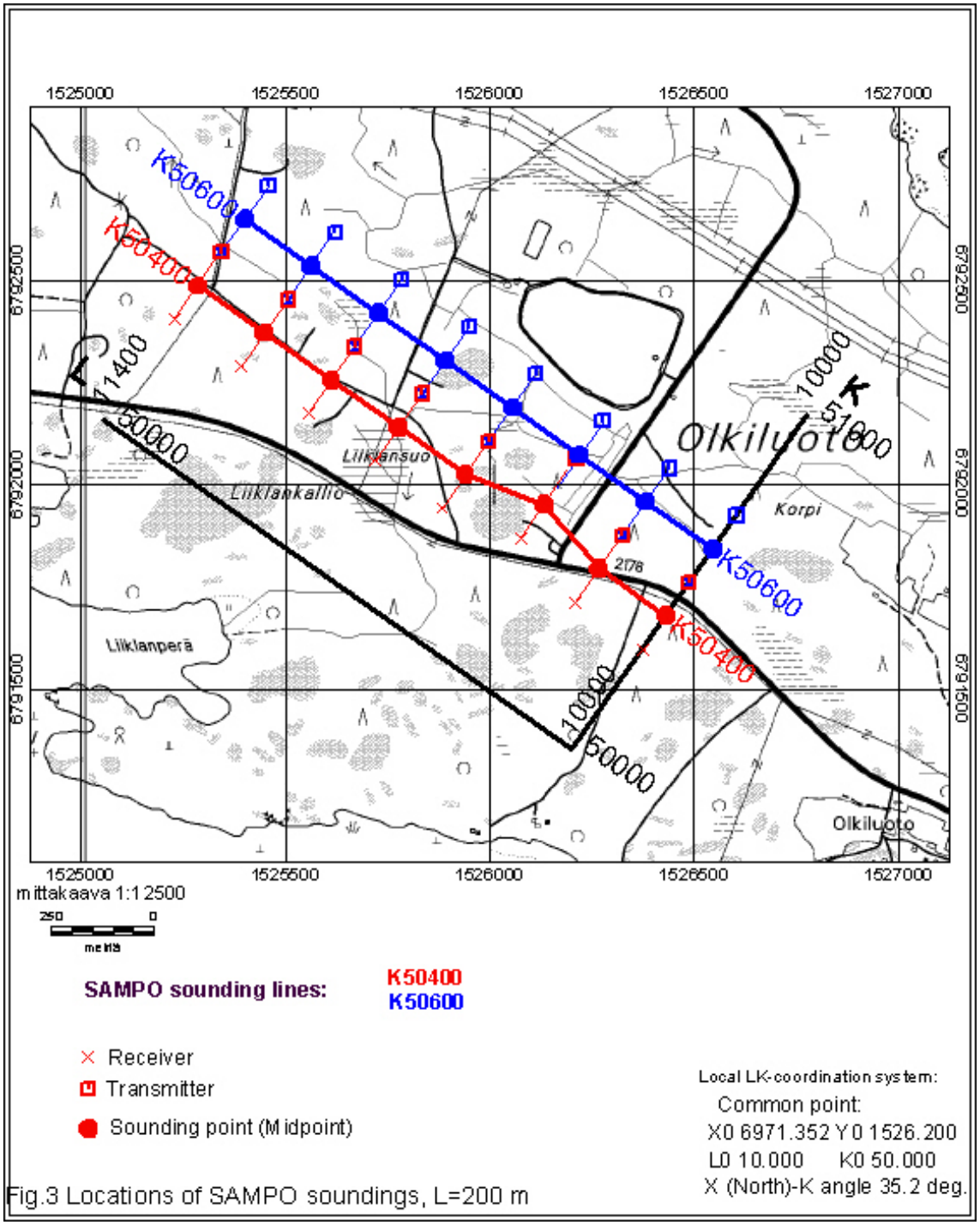

Fig.3 Locations of SAMPO soundings, L=200 m

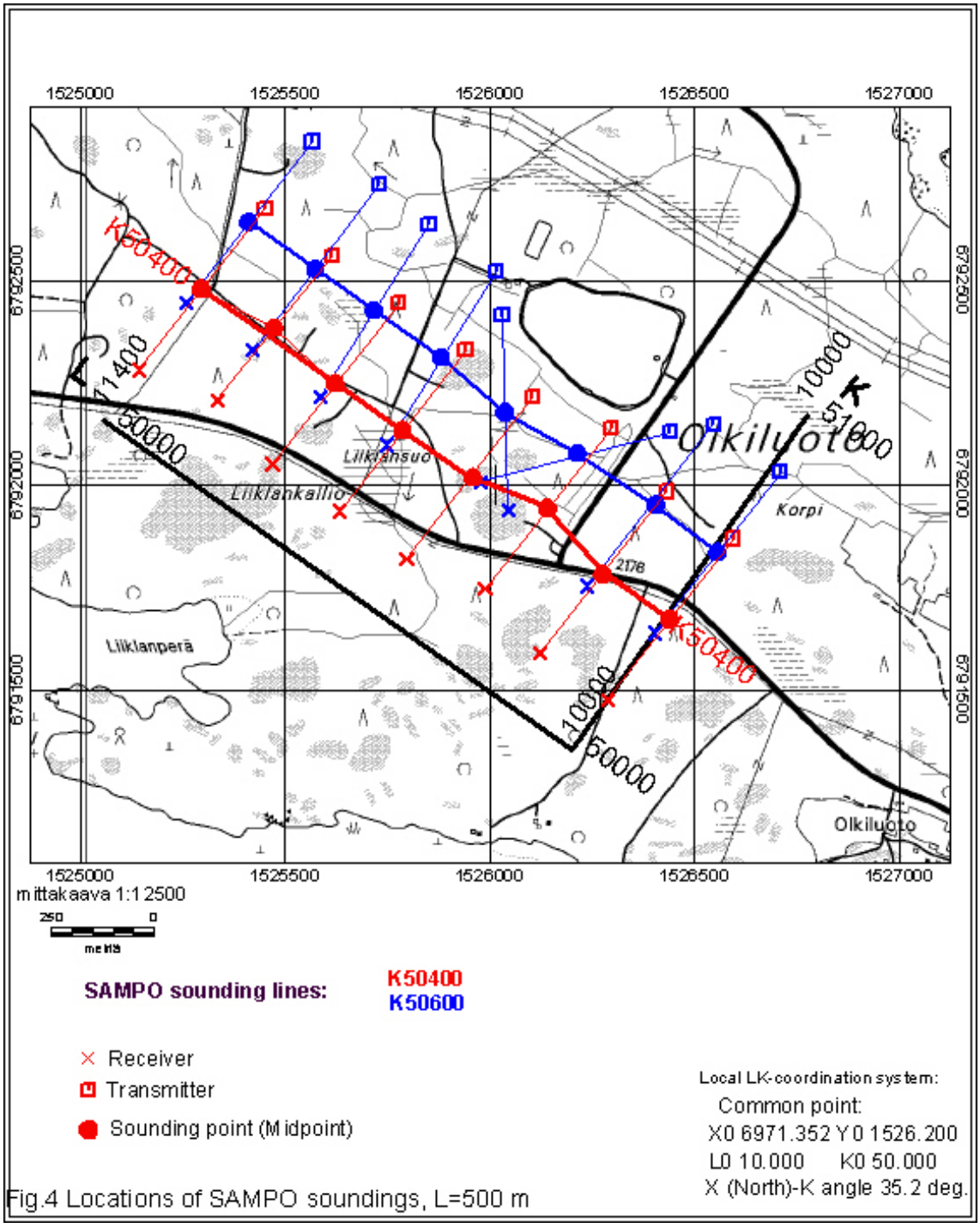

Fig.4 Locations of SAMPO soundings, L=500 m

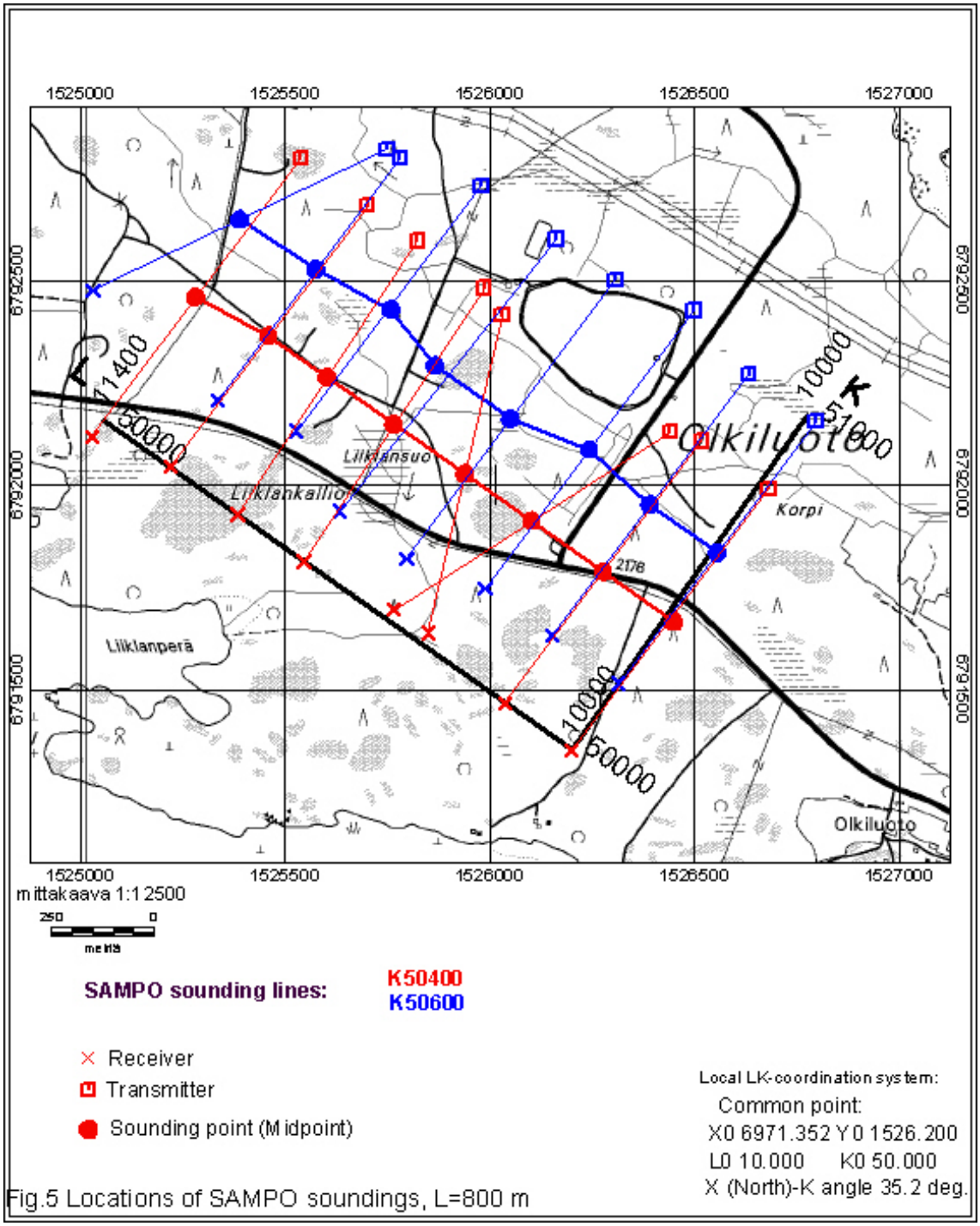

Fig.5 Locations of SAMPO soundings, L=800 m

5. DATA PRESENTATION AND STORING

SAMPO results have been processed with GTK SAMPO program (Saltandgrain , Ville Sipola, M.Sc Thesis 2002) and Geosoft OASIS GTK SAMPO GX (Arto Korpisalo 2005).
Principle of the data processing is described in the chapter 3 of this report.

The tilt corrected ARD results are presented in appendices 4-9 (6 profiles, scale 1:5000).
The profiles include both the 2005 (red curves) and 2006 (blue curves) sounding curves.
In the figures 7-12 the results of some separate sounding sites, 2004-2006, have been presented.

SAMPO sounding data has been collected in 6 broadside line files (ASCII):

2005_K50400_200.sam (Line K50400, coil separation 200 m)
2005_K50400_500.sam (Line K50400, coil separation 500 m)
2005_K50400_800.sam (Line K50400, coil separation 800 m)
2005_K50600_200.sam (Line K50600, coil separation 200 m)
2005_K50600_500.sam (Line K50600, coil separation 500 m)
2005_K50600_800.sam (Line K50600, coil separation 800 m)

SAMPO sounding data is stored on CD disc including the data folders for every measurement day (30.5-3.6) and the summary folder including the 6 line files and the OASIS data bases.

6. COMPARISON OF THE 2004 - 2006 RESULTS

Examples of 2004, 2005 and 2006 results are presented in the figures 7-12. The figures 7-8 show soundings with 200 m coil separation, figures 9-10 500 m coil separation soundings and figure 11-12 800 m coil separation soundings. In figure 6 there is in addition to the sounding curves of three years an example of two adjacent soundings at the same site. The test shows that the repeatability of adjacent measurements is good in spite of the 3-D effects of power lines and cables.

The Olkiluoto nuclear power plant and ONKALO region is under very active construction at the moment. At some sounding sites it has been necessary to change the location of Tx or Rx because of constructions, roads or cables. Before the comparison of the monitoring soundings it has to be checked that the sites of Rx and Tx have been the same every year. The final sounding curve is also sensitive to the tilt correction, which is based on the noisy low frequencies. The tilt correction has to be finalized 'manually' before correlation.

Compared with the 2004 curves some of the new sounding curves have likely been deformed by the new structures or by the alteration of the overburden moisture. (Fig 8. Sounding K50600/L10.20, coil separation 200 m and Fig 10. Sounding K50400/L10.0, coil separation 500 m).

The soundings have been classified in three categories according to the quality of the ADR-transformation (Appendices 1-3). The ARD-transformations with slight disturbances are marked in category one (best quality). Category three contains soundings with severe disturbances.
* (asterisk) in the quality column means that it was not possible to do the sounding, but the background measurement could be done. ** means that the site was too noisy even for the background measurement.

After three years of monitoring measurements there is enough data to screen out some monitoring sites, which are technically impossible to measure (strong EM noise) or have very strong 3-D effects. If needed some new sites could be tested to compensate the rejected sounding sites.

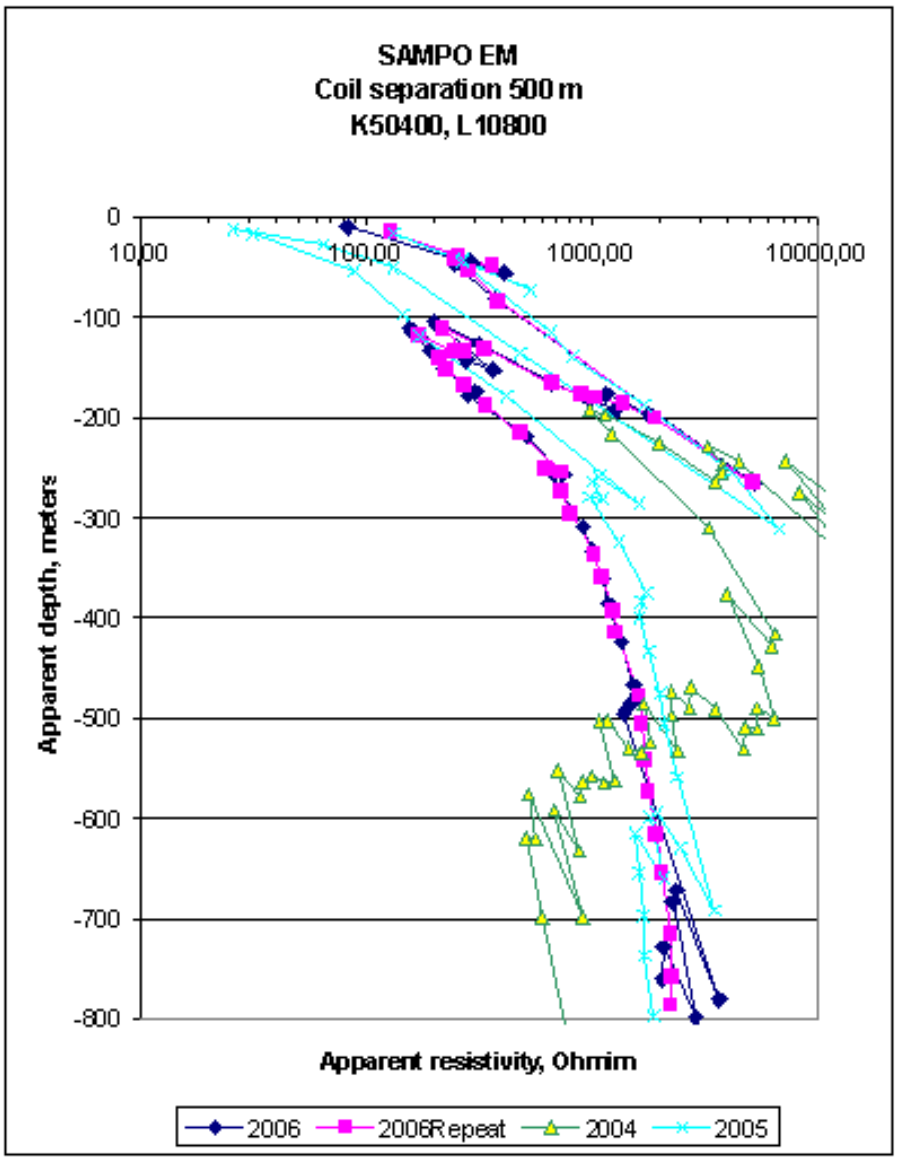

Figure 6. An example of SAMPO monitoring sounding. Green ARD-curve is the 2004 measurement, light blue is the 2005 measurement and blue and red ARD-curves are 2006 repeat measurement.

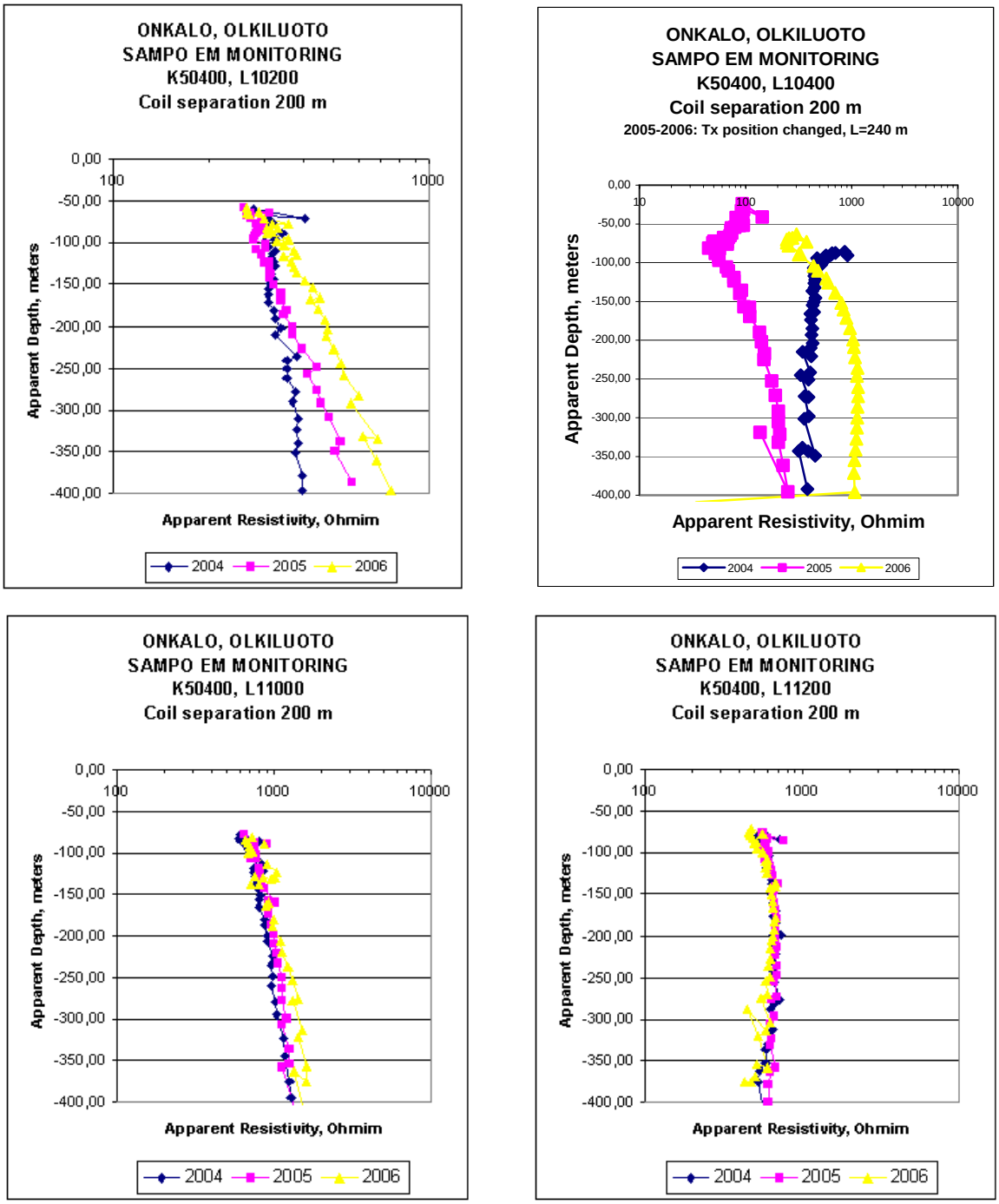

Figure 7. 4 monitoring soundings of Line K50400, coil separation 200 m

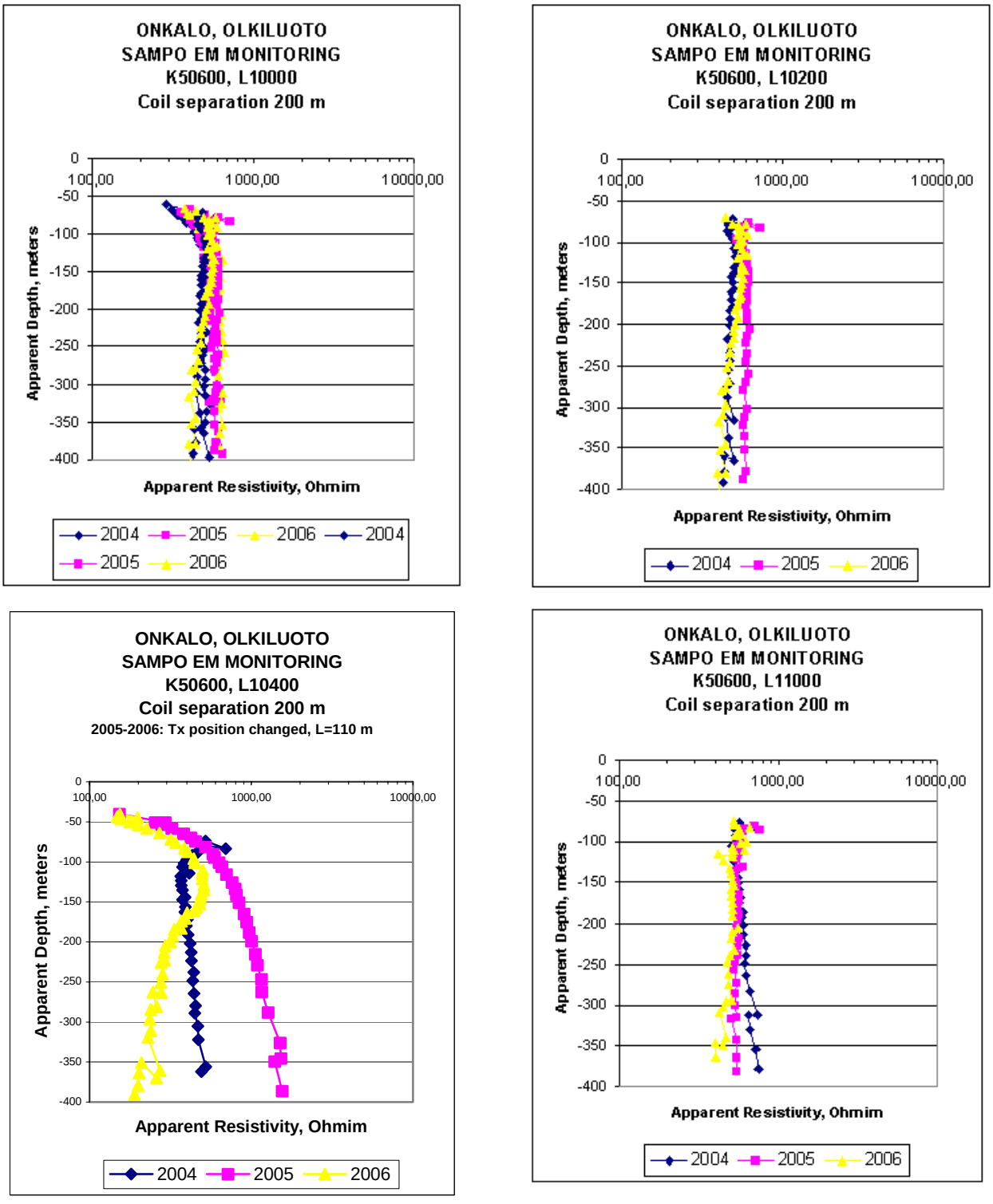

Figure 8. 4 monitoring soundings of Line K50600, coil separation 200 m

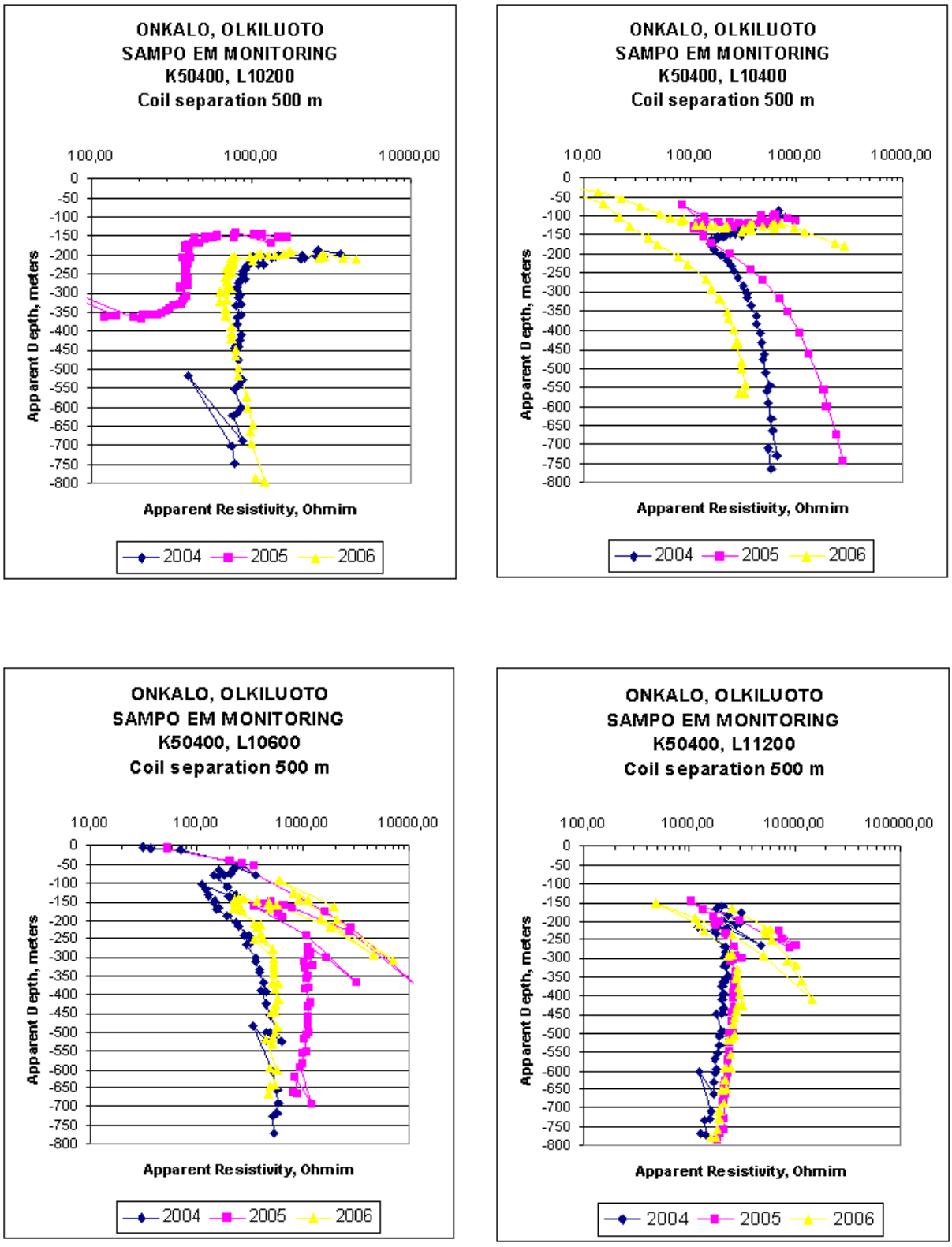

Figure 9. 4 monitoring soundings of Line K50400, coil separation 500 m

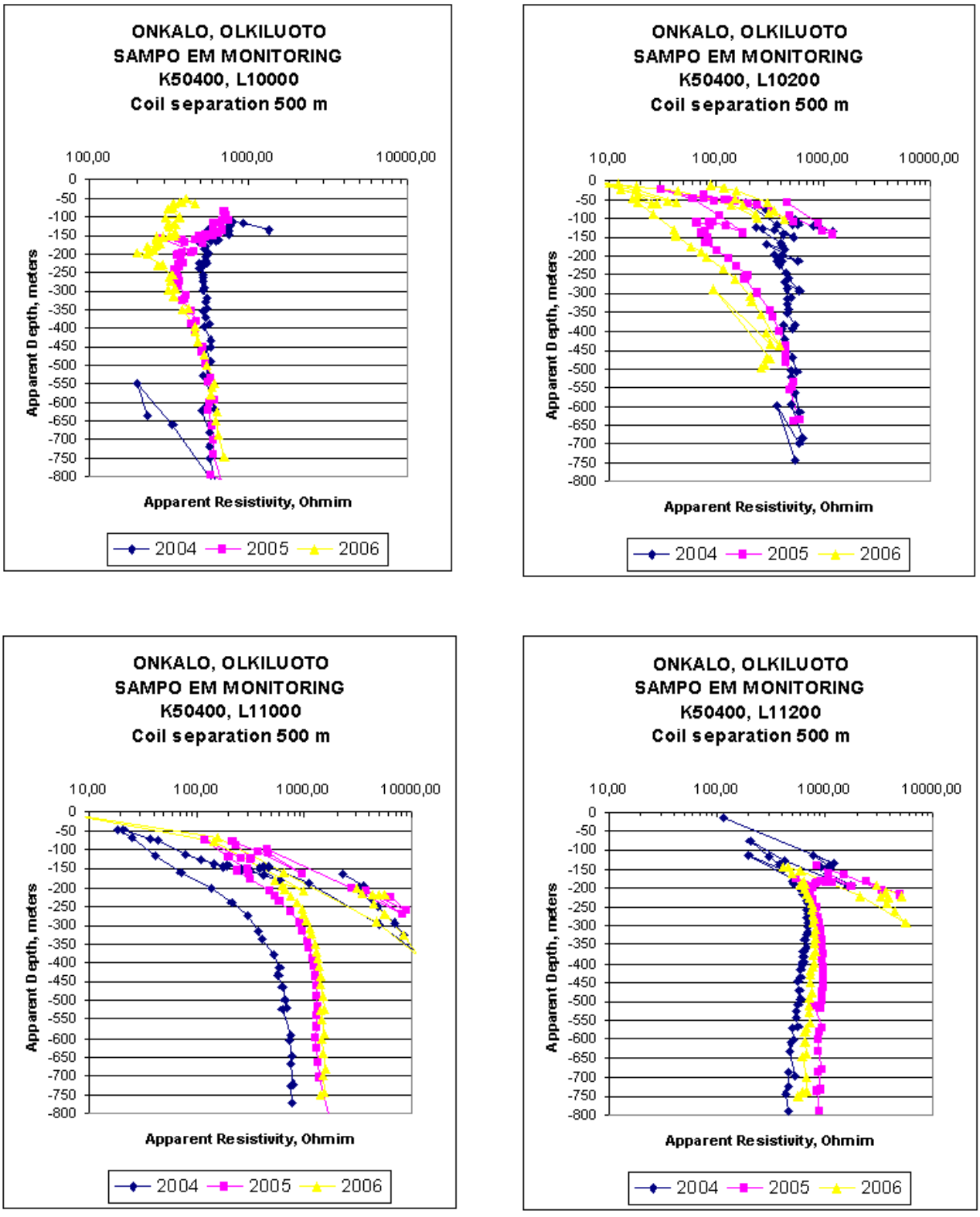

Figure 10. 4 monitoring soundings of Line K50600, coil separation 500 m

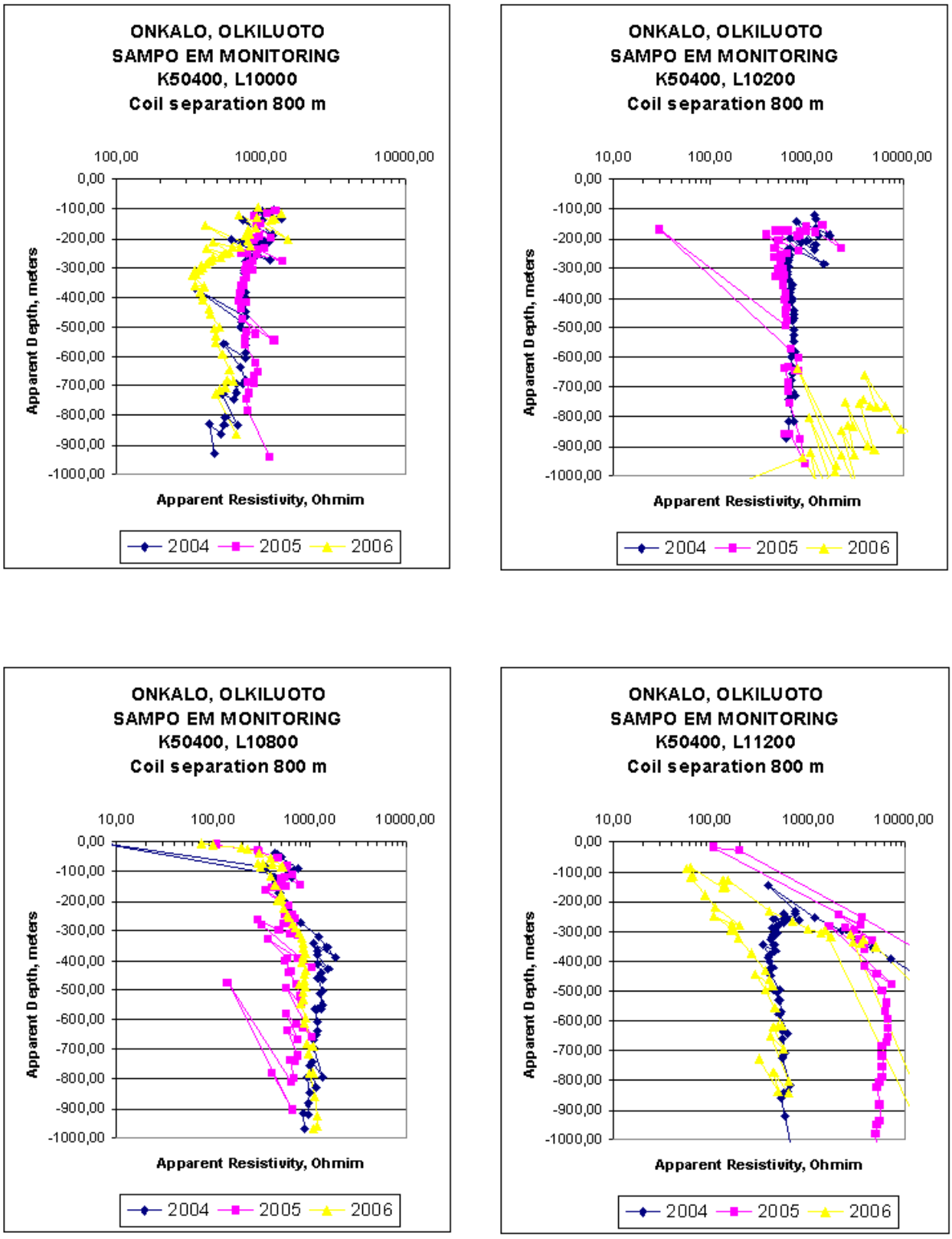

Figure 11. 4 monitoring soundings of Line K50400, coil separation 800 m

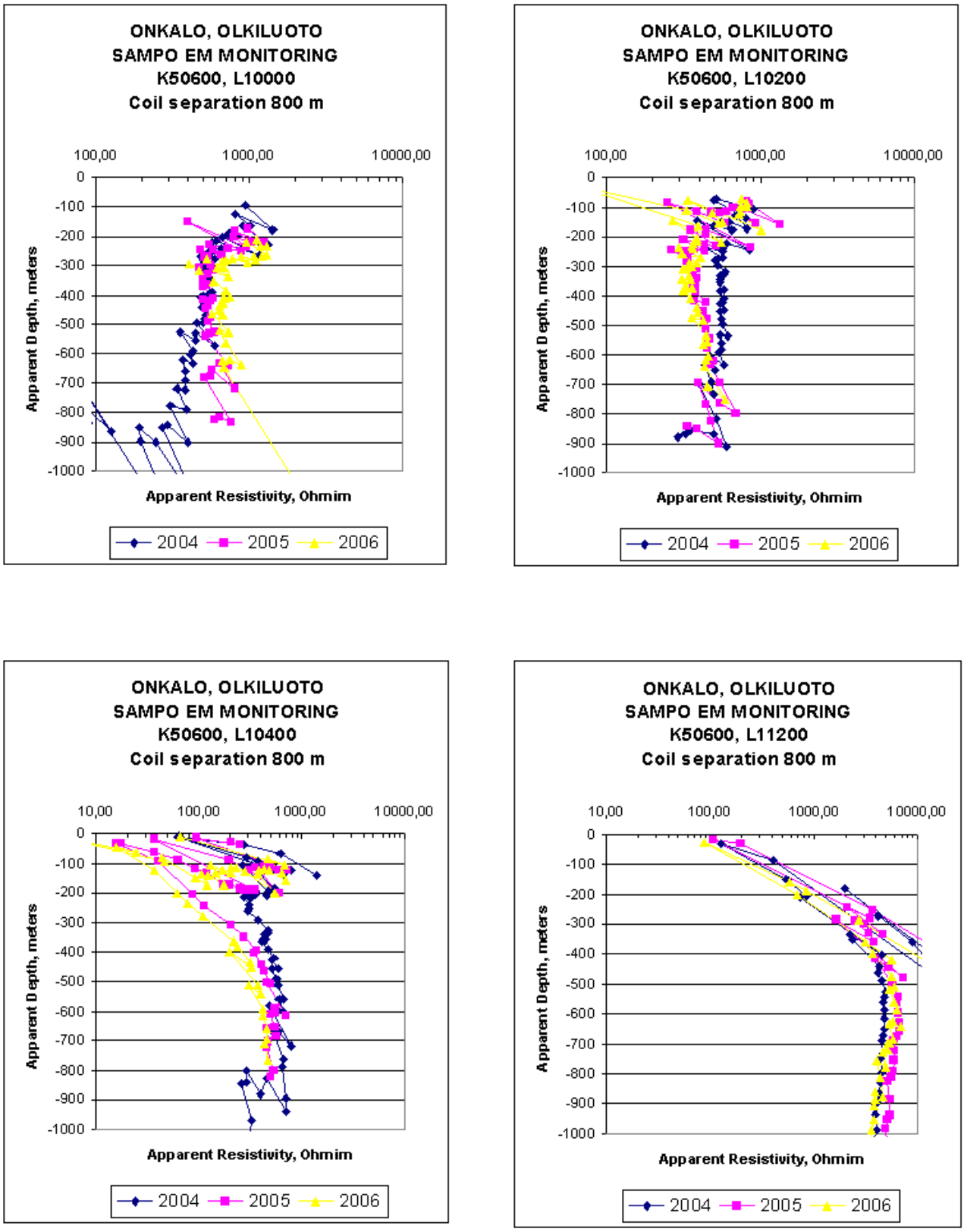

Figure 12. 4 monitoring soundings of Line K50600, coil separation 800 m

7. SUMMARY

The field work was done during one week from 29th May to 2nd June, 2006. The same marked Tx/Rx sites were used as in the previous measurements 2004 and 2005. The numerous power lines and the cables of the area caused disturbances and 3-D effects in the sounding curves. In spite of the cultural noise the repeatability of the soundings is good.

Compared with the 2004 and 2005 ARD curves some of the new sounding curves have been slightly changed. The differences may be caused by the new structures or the alteration of the moisture of soil and bedrock.

After three years of monitoring measurements there is enough data to abandon some poor monitoring sites, and to select and test new sites to compensate the rejected sites.

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APPENDICES

1. List of of SAMPO soundings, coil separation 200 m, line K50.400 and K50.600
2. List of of SAMPO soundings, coil separation 500 m line K50.400 and K60.600
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9. SAMPO ARD profile K50.600, coil separation 800 m, 2004 and 2005 results

List of of SAMPO soundings Appendix 1
Coil separation 200 m

Quality class 1: Good quality, adequate for monitoring
2: Moderate quality, adequate for monitoring
3: Bad quality, not suited for monitoring
*: No results with the transmitter only background measured
**: No results, no background measurement

Line K50.400 L=200	L	K	X	Y	Midpoint X L	Midpoint Y K	Quality Class	Note L=Coil separation
Tx	10.000	50.500	6791.761	1526.488	6791.679	1526.431	1	
Rx	10.000	50.300	6791.597	1526.373	10.000	50.400		
Tx	10.200	50.500	6791.876	1526.325	6791.794	1526.267	1	
Rx	10.200	50.300	6791.712	1526.210	10.200	50.400		
Tx	10.400	50.590	6792.032	1526.190	6791.950	1526.133	2	L=240
Rx	10.400	50.350	6791.869	1526.075	10.400	50.470		
Tx	10.600	50.500	6792.106	1525.998	6792.025	1525.940	3	
Rx	10.600	50.300	6791.943	1525.883	10.600	50.400		
Tx	10.800	50.500	6792.222	1525.835	6792.140	1525.777	* *	No results
Rx	10.800	50.300	6792.058	1525.719	10.800	50.400		
Tx	11.000	50.500	6792.337	1525.671	6792.255	1525.613	1	Repeated sound.
Rx	11.000	50.300	6792.174	1525.559	11.000	50.400		
Tx	11.200	50.500	6792.452	1525.508	6792.371	1525.450	1	
Rx	11.200	50.300	6792.289	1525.392	11.200	50.400		
Tx	11.400	50.500	6792.568	1525.344	6792.486	1525.287	*	No results
Rx	11.400	50.300	6792.404	1525.229	11.400	50.400		Background meas.

Line K50.600 L=200	L	K	X	Y	Midoint X L	Midpoint Y K	Quality Class	Note
Tx	10.000	50.700	6791.924	1526.604	6791.842	1526.546	1	
Rx	10.000	50.500	6791.761	1526.488	10.000	50.600		
Tx	10.200	50.700	6792.039	1526.440	6791.958	1526.382	1	
Rx	10.200	50.500	6791.876	1526.325	10.200	50.600		
Tx	10.400	50.700	6792.155	1526.277	6792.073	1526.219	2	L=110
Rx	10.400	50.590	6791.991	1526.161	10.400	50.645		
Tx	10.600	50.700	6792.270	1526.113	6792.188	1526.057	*	No results
Rx	10.600	50.500	6792.106	1525.998	10.600	50.600		
Tx	10.800	50.700	6792.385	1525.950	6792.303	1525.892	3	
Rx	10.800	50.500	6792.222	1525.835	10.800			
Tx	11.000	50.700	6792.500	1525.786	6792.419	1525.729	2	
Rx	11.000	50.500	6792.337	1525.671	11.000			
Tx	11.200	50.700	6792.616	1525.623	6792.534	1525.565	1	
Rx	11.200	50.500	6792.452	1525.508	11.200			
Tx	11.400	50.700	6792.731	1525.460	6792.649	1525.402	**	No results
Rx	11.400	50.500	6792.568	1525.344	11.400			

List of of SAMPO soundings Appendix 2
Coil separation 500 m

Quality class 1: Good quality, adequate for monitoring
2: Moderate quality, adequate for monitoring
3: Bad quality, not suited for monitoring
*: No results with the transmitter, only background measured
**: No results, no background measurement

Line K50.400 K=500	L	K	X	Y	Midpoint X L	Midpoint Y K	Quality Class	Note
Tx Rx	9.975 10.000	50.650 50.150	6791.869 6791.475	1526.595 1526.287	6791.671 9.988	1526.441 50.600	1	Repeated sound.
Tx Rx	10.175 10.200	50.650 50.150	6791.984 6791.590	1526.432 1526.123	6791.7807 10.188	1526.277 50.600	1(2)	
Tx Rx	10.375 10.400	50.700 50.200	6792.140 6791.746	1526.297 1525.988	6791.943 10.388	1526.142 50.650	2 (3)	
Tx Rx	10.575 10.600	50.650 50.150	6792.215 6791.820	1526.105 1525.796	6792.018 10.588	1525.950 50.600	3 (2)	
Tx Rx	10.775 10.800	50.650 50.150	6792.330 6791.936	1525.941 1525.633	6792.133 10.788	1525.787 50.600	3	Repeated sound.
Tx Rx	10.975 11.000	50.650 50.150	6792.445 6792.051	1525.778 1525.469	6792.248 10.988	1525.623 50.600	3	
Tx Rx	11.175 11.200	50.650 50.190	6792.560 6792.166	1525.615 1525.306	6792.384 11.188	1525.474 50.625	2	Repeated sounding
Tx Rx	11.375 11.400	50.650 50.150	6792.676 6792.282	1525.451 1525.142	6792.479 11.488	1525.296 50.600	**	No results

Line K50.600 L=500	L	K	X	Y	Midpoint X L	Midpoint Y K	Quality Class	Note
Tx Rx	9.975 10.000	50.850 50.350	6792.032 6791.638	1526.710 1526.402	6791.835 9.988	1526.557 50.600	1	Repeated sound.
Tx Rx	10.175 10.200	50.850 50.350	6792.148 6791.753	1526.547 1526.238	6791.971 10.188	1526.407 50.600	2(3)	
Tx XY Rx	10.252 10.560	50.774 50.407	6792.130 6792.007	1526.440 1525.977	6792.077 10.406	1526.215 50.590	2	
Tx XY Rx	10.753 10.464	50.798 50.399	6792.415 6791.906	1526.030 1526.045	6792.177 10.608	1526.038 50.598	3	
Tx Rx	10.825 10.800	50.850 50.350	6792.522 6792.099	1526.016 1525.748	6792.311 10.813	1525.882 50.600	* *	No results
Tx Rx	11.025 11.000	50.850 50.350	6792.637 6792.214	1525.852 1525.585	6792.426 11.013	1525.718 50.600	3	Backround measured
Tx Rx	11.175 11.200	50.850 50.350	6792.734 6792.330	1525.730 1525.421	6792.527 11.188	1525.575 50.600	2	
Tx Rx	11.375 11.400	50.850 50.350	6792.839 6792.445	1525.566 1525.258	6792.642 11.388	1525.412 50.600	* *	No results

List of of SAMPO soundings
Coil separation 800 m

Appendix 3

Quality class 1: Good quality, adequate for monitoring
2: Moderate quality, adequate for monitoring
3: Bad quality, not suited for monitoring
*: No results with the transmitter, only background measured
**: No results, no background measurement

Line K50.400 K=800	L	K	X	Y	Midpoint Y L	Midpoint X K	Quality Class	Note
Tx Rx	9.975 10.000	50.800 50.000	6791.991 6791.352	1526.682 1526.200	6791.665 9.988	1526.451 50.400	2	
Tx Rx	10.175 10.200	50.800 50.000	6792.107 6791.467	1526.518 1526.037	6791.787 10.188	1526.277 50.400	2	
Tx XY Rx	10.252 10.553	50.774 50.030	6792.152 6791.695	1526.536 1525.765	6791.912 10.403	1526.103 50.402	2	
Tx XY Rx	10.752 10.452	50.771 50.031	6792.430 6791.638	1526.016 1525.849	6792.027 10.601	1525.940 50.401	3	Repeated sound.
Tx Rx	10.825 10.800	50.800 50.000	6792.481 6791.813	1525.987 1525.546	6792.148 10.813	1525.766 50.400	2	
Tx Rx	11.025 11.000	50.800 50.000	6792.597 6791.928	1525.824 1525.383	6792.263 11.013	1525.603 50.400	3	
Tx Rx	11.175 11.200	50.800 50.000	6792.683 6792.044	1525.701 1525.219	6792.364 11.188	1525.460 50.400	2(3)	
Tx Rz	11.400 11.400	50.800 49.950	6792.798 6792.118	1525.538 1525.027	6792.459 11.400	1525.282 50.375	**	No results

Line K50.600 K=800	L	K	X	Y	Midpoint Y L	Midpoint X K	Quality Class	Note
Tx Rx	9.975 10.000	51.000 50.200	6792.155 6791.515	1526.797 1526.315	6791.834 9.988	1526.557 50.600	2 (1)	Repeated sound.
Tx Rx	10.175 10.200	51.000 50.200	6792.270 6791.631	1526.633 1526.152	6791.951 1.188	1526.392 50.600	2 (1)	
Tx Rx	10.375 10.400	51.050 50.200	6792.426 6791.746	1526.499 1525.988	6792.086 10.388	1526.243 50.625	2 (3)	
Tx Rx	10.575 10.600	51.000 50.150	6792.501 6791.820	1526.307 1525.796	6792.161 10.588	1526.051 50.575	3 (2)	
Tx Rx	10.750 10.800	51.000 50.150	6792.645 6791.936	1526.102 1525.633	6792.291 10.775	1525.867 50.575	3	Tx placement changed
Tx Rx	10.975 11.000	51.000 50.250	6792.731 6792.133	1525.980 1525.527	6792.428 10.988	1525.760 60.625	2 (3)	Repeated sound. Bacground meas. L=750 m
Tx Rx	11.175 11.200	50.940 50.190	6792.846 6792.207	1525.816 1525.335	6792.527 11.188	1525.576 50.570	3	
Tx XY Rz	11.214 11.603	50.940 50.243	6792.820 6792.475	1525.750 1525.030	6792.648 11.409	1525.390 50.592	3	