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ZTEM SURVEY IN THE OUTOKUMPU REGION

by

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Geotech Ltd. carried out a helicopter-borne geophysical survey for the Geological Survey of Finland over the Outokumpu Mining Camp area in 2013. Geophysical sensors included a Z-axis tipper electromagnetic (ZTEM) system, and a caesium magnetometer. A total of 1250 line-kilometers of geophysical data were acquired during the survey. The line spacings were 2 km, 1 km and 500 m.

The delivered survey results included in- and cross-line ZTEM tipper components at six frequencies (25, 37, 75, 150, 300 and 600 Hz), total magnetic intensity data, and various derivatives of ZTEM tipper data. 2D inversion tests over selected lines were performed by the contractor in support of the ZTEM survey results. Additional inversions were purchased from the contractor after the survey: 2D inversions from all survey lines, 3D inversion with a large cell size from the whole survey area, and high resolution 3D inversion from the area with 500 m line spacing.

Here, we present an overview of the ZTEM survey and compare the delivered inversion results. Although the results are generally in good agreement, the 3D inversion model with the finest mesh yields the best results. The inversion models are used in other papers of this volume.

Keywords: Electromagnetic methods, airborne methods, ZTEM, geophysics, geophysical surveys, three-dimensional models, Outokumpu

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INTRODUCTION

The ZTEM or *Z-Axis Tipper Electromagnetic* system is variant of the electromagnetic (EM) airborne tipper AFMAG method (Ward 1959) for studying the electrical conductivity of bedrock in the depth range of 0 – 2 km. The method uses the natural or passive fields of the Earth as the source of transmitted energy. The naturally occurring audio frequency magnetic fields are used as the source of the primary field signal. The primary field is usually ~ 1 Hz - 1 kHz, derived from worldwide atmospheric thunderstorm activity, and propagates vertically up to several kilometers into the earth. This magnetotelluric (MT) skin depth is directly proportional to the ratio of the bedrock resistivity to the frequency. (Sattel & Witherly 2012a,b, Legault et al. 2009a,b, Holtham & Oldenburg 2010, 2012, Geotech technical reports and presentations).

In ZTEM system, the vertical magnetic field component (H_z) is recorded by a sensor mounted on a bird towed by a helicopter (Fig. 1). The vertical magnetic field component (H_z) is caused by lateral conductivity contrasts in the Earth. The ZTEM base station deployed in this survey consisted of three orthogonal coils. The fields measured by these coils provide horizontal X and Y components of the magnetic reference field, which is further used with the airborne coil data to calculate the in-line and cross-line tipper component (T_{zx} and T_{zy}) field data.

The aim of the ZTEM survey was especially to test the capability of the ZTEM system in deep exploration. A challenge was to test how well very narrow geological units could be verified from ZTEM inversion results.

Fig. 1. ZTEM system in Outokumpu. Lowermost sensor is the receiver coil having a 7.4 meter diameter. Magnetic field sensor is situated 15 meters above the coil. The total length of the cable is 85 meters. Photo: Aimo Ruotsalainen, GTK.

SURVEY

The survey was planned to cover the Outokumpu and Miihkali formations to support the Developing Mining Camp Exploration Concepts and Technologies - Brownfield Exploration project in deep exploration targeting. The survey was funded by Geological Survey of Finland (GTK). It was regarded as useful to cover the existing deep seismic survey lines (HIRE and FIRE) in the area for comparison purposes. The survey line plan (Fig. 2) was a difficult compromise between available resources and the need for high-quality spatial information. Altogether, 1250 line kilometers

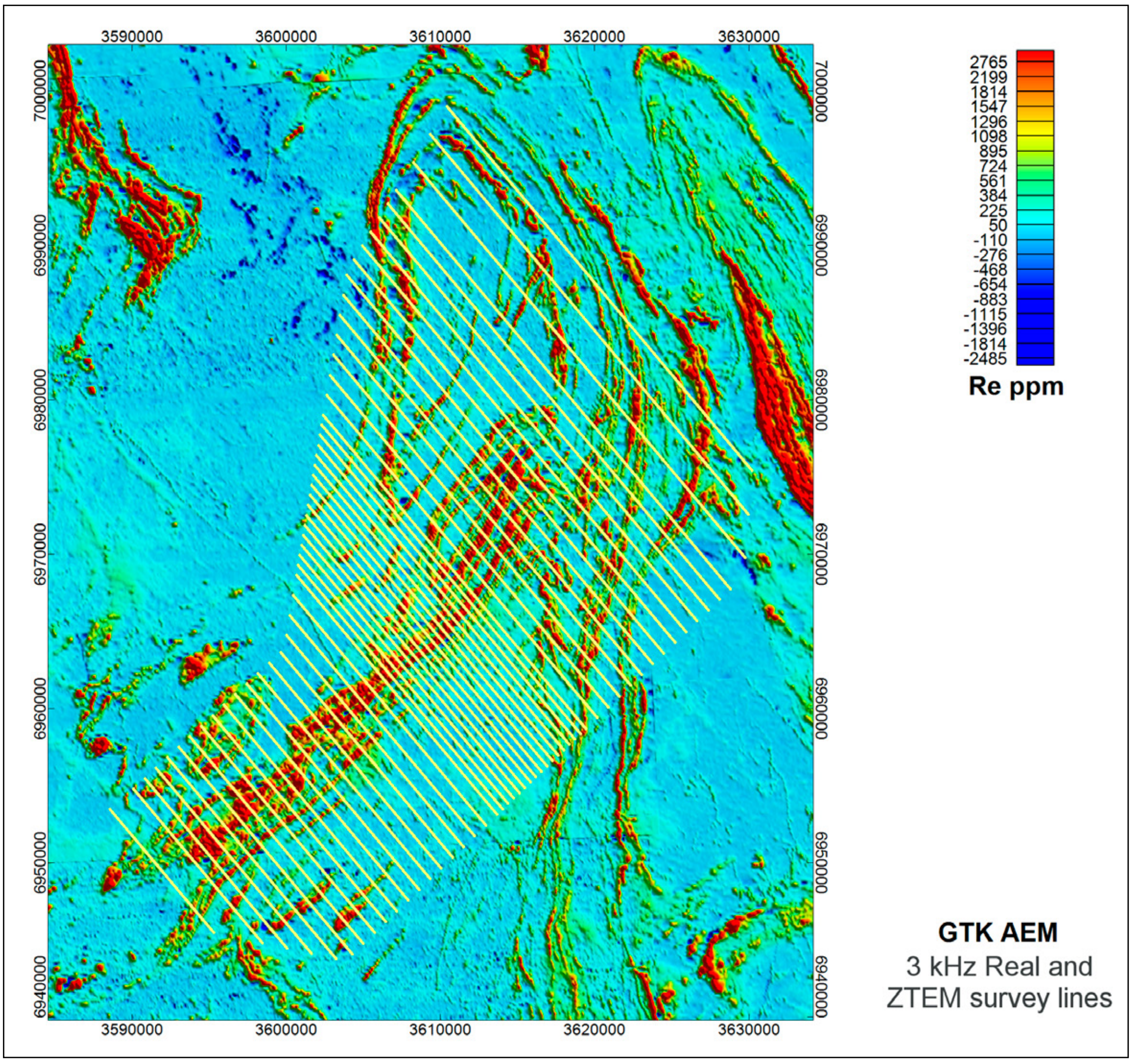

Fig. 2. ZTEM flight lines in yellow with the real component of GTK's airborne electromagnetic 3 kHz measurement.

were flown during the survey. The central area was flown with 500 m line spacing, and elsewhere with 1 km spacing, while the furthermost lines had line spacing of even 2 km. The line direction was 140 degrees, roughly SE-NW. It was understood that cultural noise could have a marked influence on the results, as two major and several minor power lines cross the area, and many other sources of electromagnetic disturbance also exist, such as industrial plants, active mines and Outokumpu town.

The helicopter flights were conducted in June 2013 during six active days. The survey was operated by Geotech Ltd. Joensuu airport acted as the main base for the helicopter, and the base station was situated inside the survey area, in a remote, uninhabited and electrically quiet location. The base station measured the horizontal X and Y magnetic components of the electromagnetic field, and this reference field was further utilized in data processing. In-field data quality assurance and preliminary processing were carried out on a daily basis during the data acquisition phase. Preliminary and final data processing, including the generation of the final digital data and map products, were undertaken from the office of Geotech Ltd. in Canada. In general, the data quality was good, as well as the ZTEM responses. The quality also depended on the primary signal recorded at the base station, which during the survey was strong. For this reason, it was possible to record 300 Hz and 600 Hz data during all flights, which could not be guaranteed beforehand.

GTK representatives received the raw data almost daily for quality control (QC) purposes and paid a visit to the survey area and the field and base stations. The operator was very helpful in providing ample information on the survey methodology and progress. The survey process was described in detail in the Technical Report (Geotech 2013a).

SURVEY DATA

The survey data included real (in-phase) and imaginary (quadrature) parts of the tipper transfer functions both in-line (Tzx) and cross-line (Tzy) at six frequencies (25, 37, 75, 150, 300 and 600 Hz) totaling 24 electromagnetic data components. The data were processed using receiver and base station coil data, corrected for the local magnetic field declination and filtered for power line monitor (PLM) and helicopter noise frequencies. The final data set included all tipper components, coordinates, elevation and terrain clearance information, total magnetic field with base station data and IGRF and Power Line Monitor (PLM) recordings (50 Hz).

The calculated EM grids provided by Geotech Ltd. were Total Divergence (DT, sum of horizontal derivatives) and Total Phase-Rotation (TPR, changes bipolar anomalies into single pole anomalies with a maximum over conductors) of all components, totaling 48 grids. The varying flight line plan caused variation in the resolution of the grids, which were interpolated with 150 m cell size.

The average terrain clearance of the helicopter ZTEM receiver coil was 95 m with standard deviation of 10 m, and due to rather windy conditions, its horizontal position and angle somewhat varied. The attitudinal position of the coil was recorded by 3 GPS antennas for internal QC and attitude correction.

The locations of the power lines were available digitally. It was noted that the PLM revealed well the main power line (110 kV transmission line) crossing the area from about SEE to NWW. The other regional power line, with a direction almost N-S in the middle of the area, was mostly recognized by PLM, but not always. According to the information from Geotech, the effect of the power line on the ZTEM results was surprisingly minor, as power lines could easily be modelled in the inversions. The reason was unclear, but might be connected with the well-grounded and precise 50 Hz frequency of the regional power line utility grid and the power lines not being major, but only 110 kV.

2D INVERSION

Prior to the inversion, the optimal resistivity for the initial model was studied. This was done by performing several 2D inversions using a broad range of initial half-space resistivities along the few selected lines. Values from 500 to 8000 Ωm were tested, and according to the input error calculation (Geotech 2013b) and discussions, the 2000 Ωm value was chosen, as this value yielded to lowest RMS misfit values.

After examination of the example inversions, the whole-data 2D inversions were performed by Geotech using Av2dtopo software. The 2D inversion uses only the in-line component T_{zx} whereas the 3D inversion utilizes both T_{zx} and the cross-line components T_{zy}. Flight lines were divided into two or three parts in which the inversions were performed. Each model mesh consisted of 440 cells laterally and 112 cells vertically, and the cell size consequently varied slightly depending on line length. The typical cell size was 20 – 30 meters.

3D INVERSIONS: WHOLE AREA

The start value test was now run for the whole area using 3D inversion software and a 1 km cell size. The tested resistivities were 1000, 2000 and 4000 Ωm (Fig. 3). Again, the start value had an effect on the model depth, and the most resistive start value gave the deepest and most resistive model. According to the previous study, the same initial resistivity value, 2000 Ωm, was chosen. Due to the large survey area and the limited cell number (max 80 x 80 x 80) of the inversion code, to achieve better resolution, the whole survey area was divided into 8 smaller overlapping sub-blocks using the method described by Holtham and Oldenburg (2012). The mesh cell size of the sub-blocks was 250 x 300 x 50 m and the initial resistivity value was 2000 Ω. The sub-block inversion models were merged together using the Geosoft Oasis Merge-Voxel function. The resistivity value range for the model was 100 – 40 000 Ωm.

The 3D inversion model was congruent with the known geology in the middle area of 500 m line spacing, but was sometimes inconsistent in the

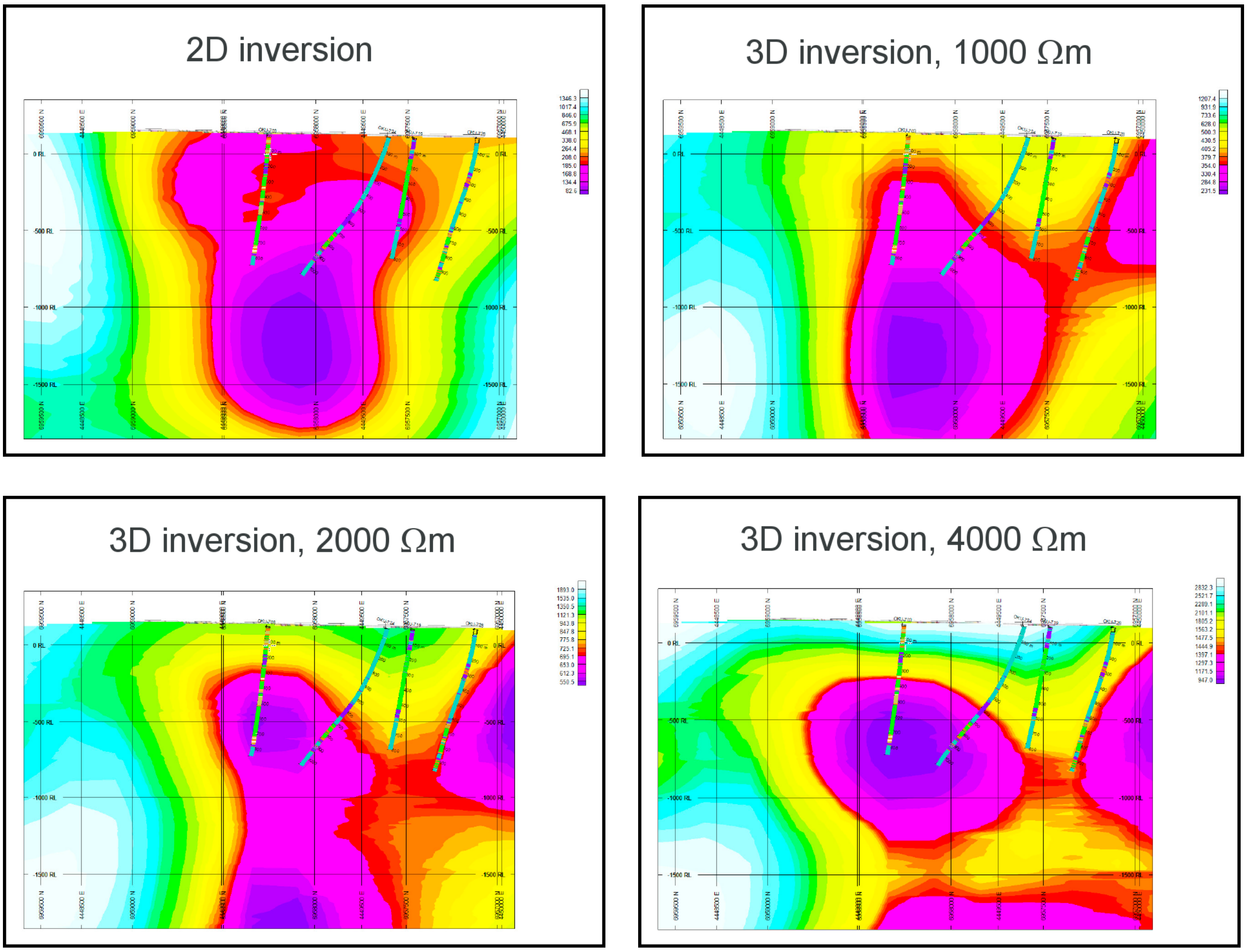

Fig. 3. 2D inversion and initial resistivity value tests of 3D inversion. White denotes the most resistive, and violet the most conductive structures. In boreholes, a dark violet colour refers to black schist, which correlates well with the 3D boundaries with all tested initial resistivity values. Borehole information is from the GEOMEX database (Anonymous 2006).

area of 1–2 km line spacing. The lithology of the boreholes is described in the GEOMEX database (Anonymous 2006), which is a result of a large research project GEOMEX in 1999–2003 in the Outokumpu area (Kontinen et al. 2006). Like the 2D inversion, all 3D inversions were performed by Geotech.

3D INVERSION: FINE MESH IN THE CENTRAL AREA

A sub-area was selected for detailed inversion in order to obtain a better understanding of 3D inversion possibilities and to try to enhance the resolution of the results (Fig. 4). The 3D inversion was carried out using a much finer mesh: a cell size of 50m along line, 50m vertically and 250m across the lines. The selected area had been flown with 500m line spacing. The cell size effect was tested, and with this line spacing and geology it was noted that the smaller cross-line cell size of 125m did improve the results slightly. In this area, the wider model resistivity range between 1 and 100 000 Ωm was utilized.

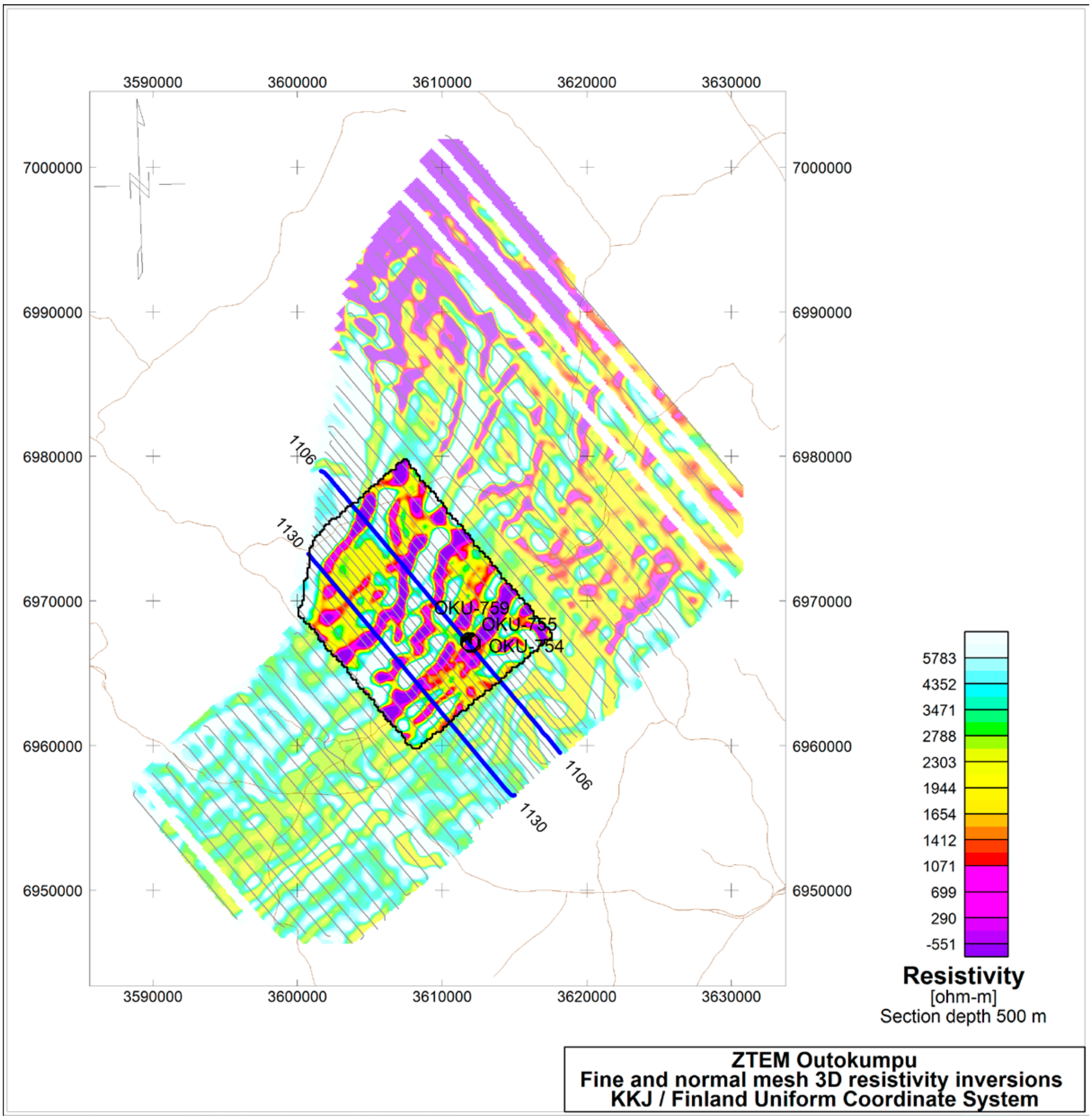

Fig. 4. Fine mesh and normal 3D resistivity inversions: Resistivity at the depth of 500 m. The fine mesh inversion area is outlined by a black line. Both resistivity grids have the same colour scale, but the fine mesh 3D inversion results are presented in brighter colours than the result of the normal 3D inversion. Grey lines are the flight lines. Lines 1106 and 1130 (highlighted in blue) and boreholes OKU-754, OKU-755 and OKU-759 are used in the comparison of the inversions. Contains data from the National Land Survey of Finland Topographic Database 03/2013.

DISCUSSION AND CONCLUSIONS: COMPARISONS IN THE OUTOKUMPU SURVEY AREA

Figure 5 compares the three different inversions along line L1106, whose location is presented in the Figure 4. The topmost panel displays 3D inversion with a 50 m cell size, the middle panel 3D inversion with a 250 m cell size and the lowest panel 2D inversion. As mentioned above, the 3D inversion with a 50 m cell size was a test and is only available for a subarea of the whole Outokumpu study area.

The location of the conductors is rather similar in all inversions, but the depth extent varies considerably. Conductive zones are notably larger in 2D inversion than either of the 3D inversions, i.e the resolution is better in 3D inversion than in 2D inversion. The 2D inversion combines some conductors that are seen as separate bodies in the 3D inversions.

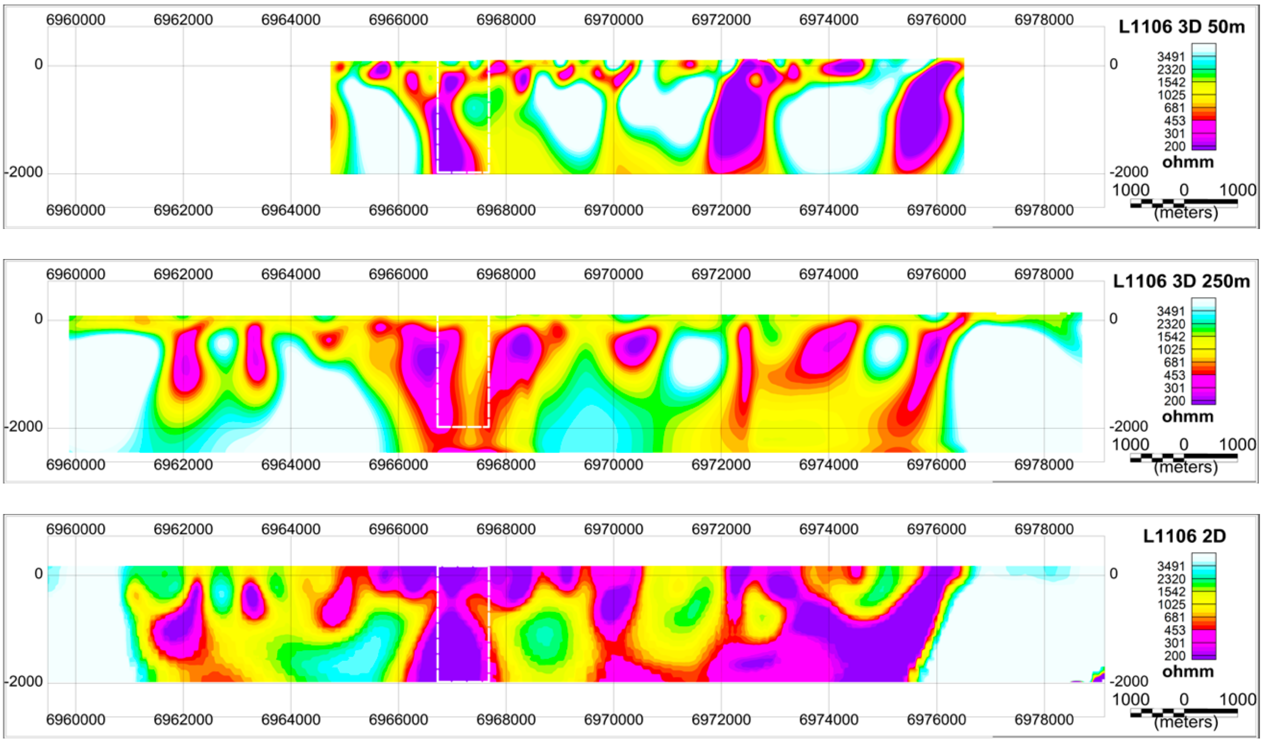

Fig. 5. Comparison of inversions on line 1106: upper panel 3D with 50 m cell, middle panel 3D with 250 m cell size and lower panel 2D (view to SW). White dashed lines outline the area that will be considered in more detail in the Figure 6.

Figure 6 presents a detail from line L1106. As one would assume, the 3D inversion with the smallest cell size shows the most detail. The 3D inversion with a larger cell size also has the conductor on the left side, but there is no sign of the near surface conductor on the right side. The 2D inversion has no resolution power in this area. Comparison with drillholes illustrates the different scales of inversions and lithology. Whereas inversions mostly show large and round conductive areas, the real lithology is complex and full of details (Anonymous 2006). The boreholes in the figure are located about 140 m to the NE of the flight line and they do not therefore represent the exact geology under the flight line. In general, black schists and sulphides have low resistivity and can thus be interpreted as conductors in this type of data. The lowest resistivities of the blackshists in the main Outokumpu zone and Miihkali area are of the magnitude of 10^{-2}–10^{-1} Ωm but not all the blackschists are conductive (Lehtonen 1981).

Figure 7 compares inversion results on line L1130, whose location is also presented in the Figure 4. At location N697 0000, the 3D inversion with a 250 m cell size shows barely anything conductive, whereas the 3D inversion with a 50 m cell size and the 2D inversion display a large and deep conductor. The resolution of 2D inversion is again poorer than in 3D inversions. The observed differences could be also partly explained by the wider allowed resistivity ranges that were used in 2D and high resolution 3D inversions (50 m cell size).

The 3D inversion report by Geotech compares the 2D and 3D inversions on lines L1070 and L1106. This comparison also states that 3D resistivity inversion has a better resolution than 2D inversion. The report additionally includes a list of 10 interpreted conductive targets of interest. Six of these are discussed in detail in the report. In this report Geotech finds it unlikely that ZTEM would respond directly to Outokumpu deposits, but it images the black shale and serpentinite units and possibly the surrounding hydrothermal mineralized halo.

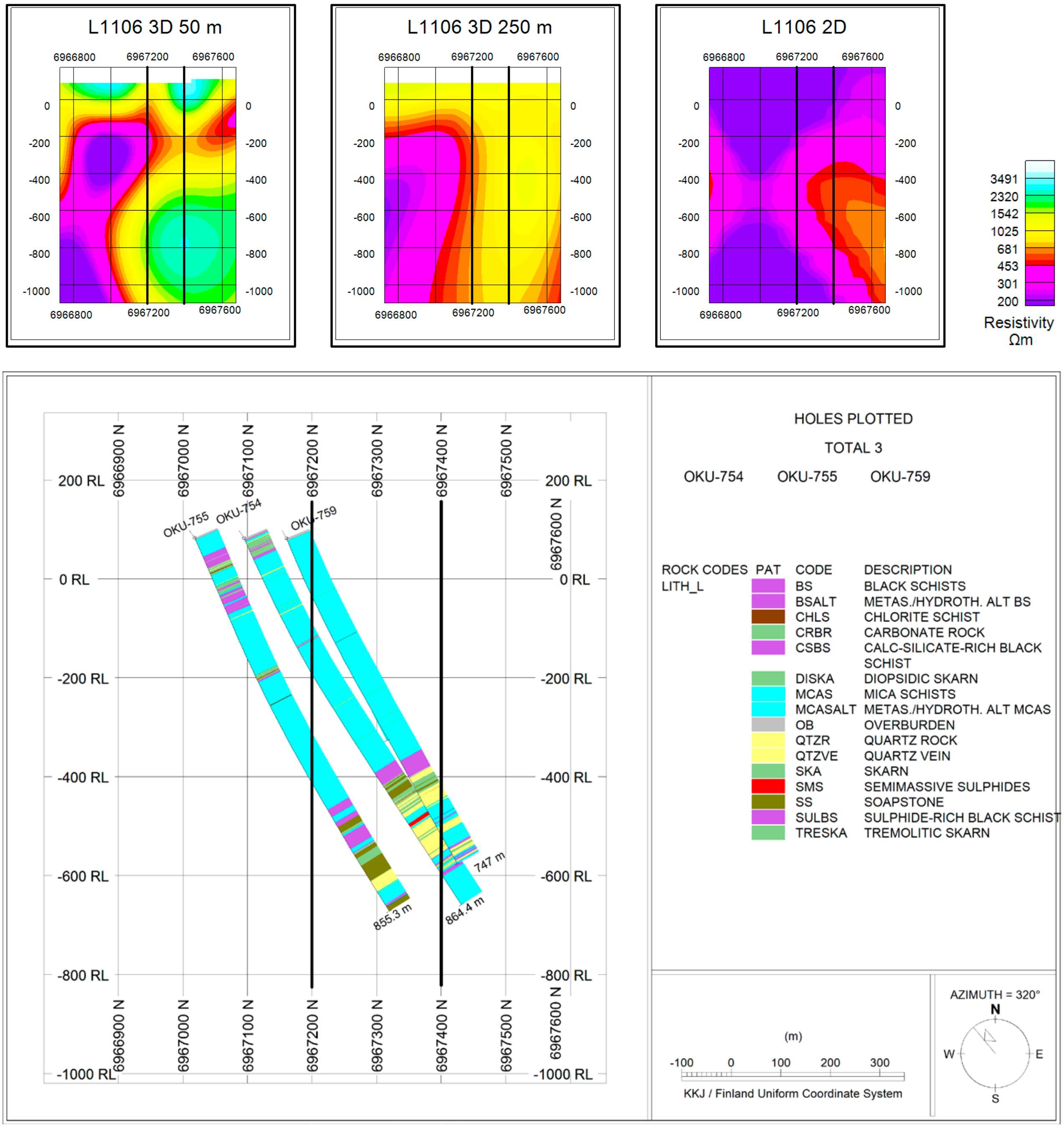

Fig. 6. A detailed view from profile L1106. The upper row presents 3D inversion slices with a 50 m cell size on the left, 3D inversion with a 250 m cell size in the middle and 2D inversion on the right. The lower row presents three drillholes and their lithology about 140 m to the NE of the flight line. Black schists (purple) and sulphides (red) are usually conductive. The view is to SW and all inversions have the same colour scale. Northings 696 7200 and 696 7400 are marked as thick black lines in all images to help comparing the locations of the images. Boreholes are from the GEOMEX database (Anonymous 2006).

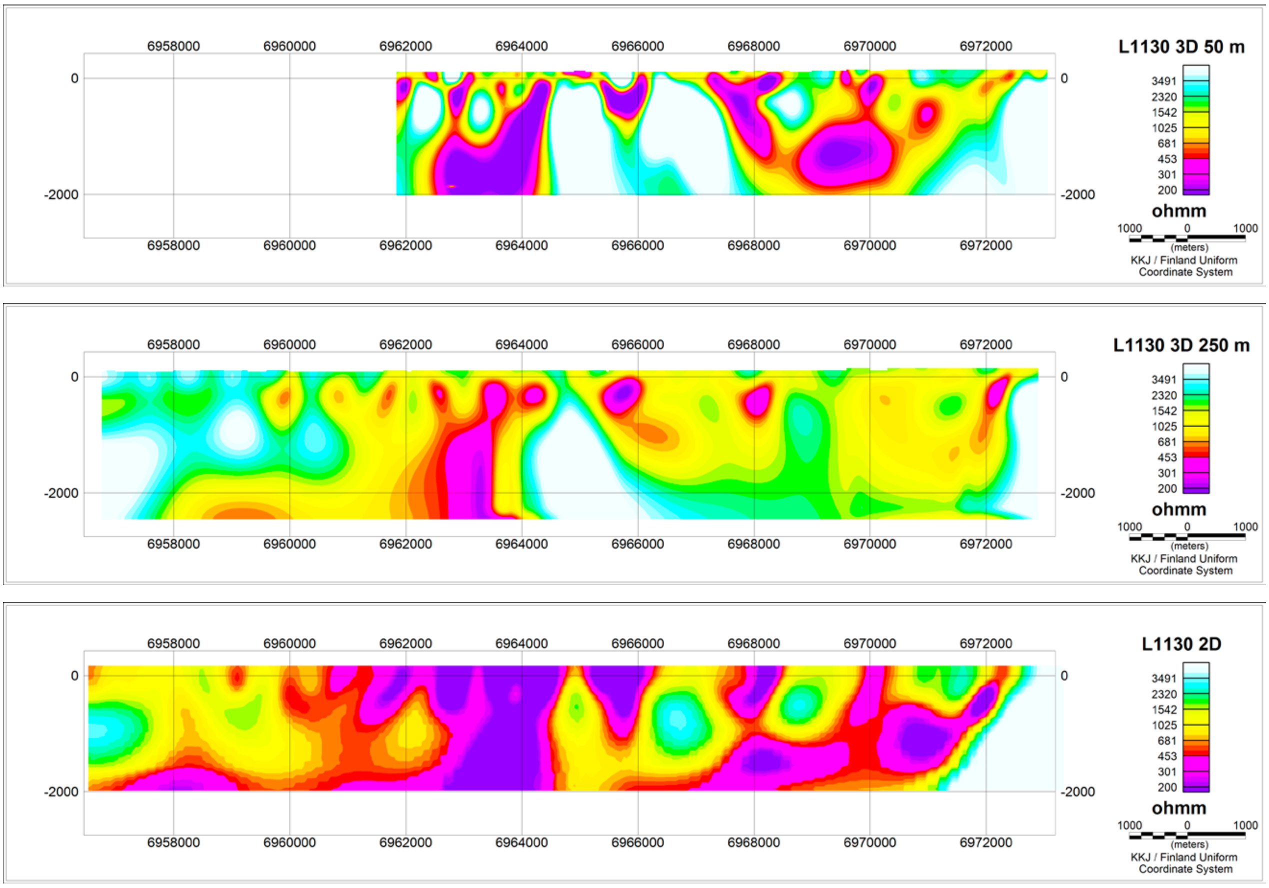

Fig. 7. Comparison of inversions L1130: upper panel 3D with a 50m cell size, middle panel 3D with a 250 m cell and lower panel 2D (view to SW).

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