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# Report on the acquisition of the new regional geophysical data in Kuusamo schist belt

## BATCircle2.0, WP1, Task 1.2.1 Novel applications of geophysical measurements

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GTK Open File Work Report

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Abstract

This report describes the fieldwork and data processing of two regional geophysical surveys carried out in the Kuusamo region in 2022 in the BATCircle2.0 project, WP1, Task 1.2.1 Novel application of geophysical measurements.

Altogether 152 magnetotelluric stations were measured covering a zone approximately 20 km wide and 60 km long in the NW-SE direction north of Kuusamo. Data processing results, including impedance tensors and tipper transfer functions, are ready for geoelectric modelling to a depth of few tens of kilometers. The same area was covered by 2378 gravity measurements made on road and snowmobile routes. The Bouguer anomaly data is ready for regional scale density modeling of the Kuusamo belt.

Keywords

Magnetotelluric methods, electromagnetic methods, gravity methods, gravity survey maps, regional, acquisition, Kuusamo Belt

Geographical area

Finland, Kuusamo

Map sheet

T513, T514, S524, S542

Other information

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**Contents**

# 1 INTRODUCTION

This report describes magnetotelluric (MT) and gravity data acquisition in the BATCircle2.0 project, WP1, Task 1.2.1 Novel application of geophysical measurements. The task aims to outline regional geological structures of the Kuusamo belt, northeastern Finland via magnetotelluric, potential field and petrophysical data. Knowledge of the large-scale structures helps to understand the geological evolution of the belt and holds clues to its mineralization processes.

During the MT field campaign data from total of 152 MT sites was acquired. Figure 1 shows locations of the acquired MT data. The processing of the raw MT data has been completed, which means that processed data (transfer functions) are available for further qualitative and quantitative analysis. Most impedance tensor transfer functions display high data quality in the period range 0.005–256 s. Preliminary modelling work has started and the results, in particular the geoelectric model of the study area, will be prepared in 2023.

The regional gravity survey was carried out between November 2021 and October 2022. A total of 2378 gravity stations were measured and processed. Measured gravity stations are mostly located along roads, but a small percentage of measurements were made on the lake's ice and snowmobile trails.

# 2 SCOPE AND PLAN OF DATA ACQUISITION

After geological and logistical considerations, an acquisition “window” was selected, which crosses the Kuusamo belt in NW–SE direction. New magnetotelluric and gravity data were acquired from roughly the same window to allow joint interpretation of the methods.

To map large scale structures of the belt, the magnetotelluric measurement plan consisted of a NW–SE oriented profile through the belt with nominal site spacing of ca. 1 km. Additionally, off-profile sites were planned on both sides of the profile with ca. 5 km site spacing so that 3D modelling could be made. The profile was intentionally extended further towards NW and SE so that data also outside of the belt as defined by surface geology could be acquired. The original plan was respected quite well during the data acquisition.

# 3 MAGNETOTELLURIC DATA ACCQUISITION

The MT data acquisition commenced in February 2022 when MT measurements were experimentally trialed on lake Yli-Kitka, which covers a large part of the measurement area. The main portion (non-lake sites) of the MT data were acquired during May–

September 2022. Data from altogether 152 MT sites exist. Additionally, remote-reference data was recorded simultaneously in Rovaniemi, which improves processed data quality. Original plan included 158 MT sites, but some were not accessible (e.g. gate on road leading to site) or the planned location had too much interfering infrastructure (e.g. powerlines).

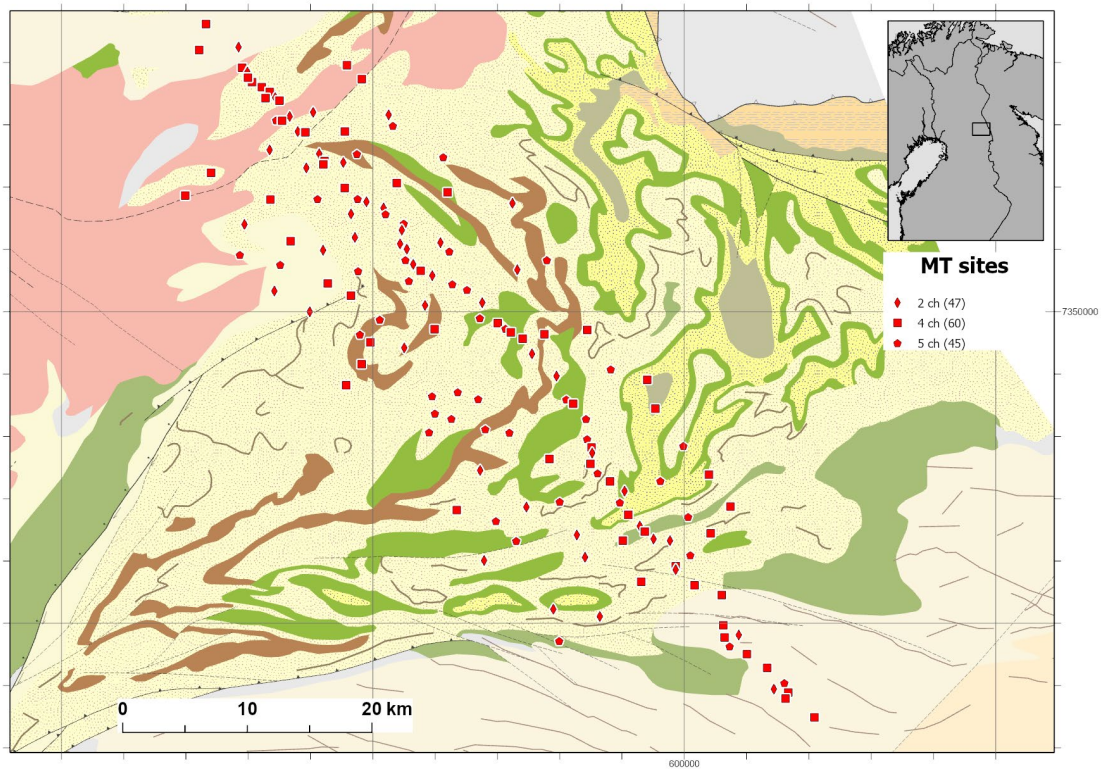


*Figure 1. Collected MT data (red symbols) on a geological map of the study area. Measurements consist of 2-channel (diamond), 4-channel (square) and 5-channel (pentagon) recordings. Data from altogether 152 MT sites exist. Coordinate system: ETRS-TM35FIN.*

## 3.1 MT survey instruments and parameters

The MT data were acquired using Metronix and ADU-08e MT systems owned by GTK. At the reference site an older ADU-07e unit was used. MFS-07e induction coils and unpolarized electrodes were used as magnetic field (H) and electric field (E) sensors, respectively. 2-, 4- and 5-channel recordings were made according to the parameters in Table 1.

*Table 1. Technical parameters for MT survey.*

| | 2-channel | 4-channel | 5-channel |
|---|---|---|---|
| Recorded field components | Ex, Ey | Ex, Ey, Hx, Hy | Ex, Ey, Hx, Hy, Hz |
| Measurement directions | X=magnetic north, Y=magnetic east, Z=vertical down | | |

| | |
|---|---|
| Nominal E-field dipole size | 100 m |
| Sampling | 128 Hz full-time, 4096 Hz 00:00–02:00 GMT |

At each site, overnight data recording was made so that minimum ca. 12 h data record exists. At few sites receiver failure resulted in shorter time series. Sampling frequency was set to 128 Hz full-time and additionally 4096 Hz sampling was used during 00:00–02:00 GMT time.

### 3.2 MT data processing

Data processing of the raw time series data was done using GTK inhouse code EMts, which uses robust (M-estimate) remote reference algorithm. In data processing all instrument related calibration factors, such as frequency dependent calibrations of each induction coil, are considered. In addition, the actual dipole size used in the electric field measurement was considered. Results of data processing are impedance tensor and tipper transfer functions:

$$\begin{pmatrix} E_x \\ E_y \end{pmatrix} = \begin{pmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{pmatrix} \begin{pmatrix} H_x \\ H_y \end{pmatrix} \qquad \text{(Impedance tensor)}$$

$$H_z = \begin{pmatrix} T_{zx} & T_{zy} \end{pmatrix} \begin{pmatrix} H_x \\ H_y \end{pmatrix} \qquad \text{(Tipper)}$$

Tipper can be processed only at sites where vertical magnetic (Hz) field was measured i.e. at 5-channel sites. 2-channel sites required simultaneous magnetic field (Hx, Hy) recording from nearby 4-channel or 5-channel site, otherwise it is not possible to define impedance tensor.

From data processing, interpretable data (transfer functions) have been obtained from all but one site. Most transfer functions display high data quality in the period range 0.005–256 s. At some sites lower quality data can be observed particularly at the MT deadband (around 1 s period). Impedance tensor and tipper data are used later in the project to obtain an electrical conductivity model of the bedrock under the study area down to several tens of kilometers.

## 4 GRAVITY DATA ACQUISITION

Geological density variations can be detected by the gravity method. The main component of the measured gravity field is the gravitational attraction of the Earth's mass. Smaller effects in gravity field are caused by the centrifugal force due to Earth's rotation, direct attraction of the Moon's mass and tidal effects. Additionally, measured

gravity field is dependent on latitude of location, measuring elevation and topography variation around the measuring station. Geology of the area has its own small effects as well. Light rock types and overburden close to measuring station reduces the gravity field. Correspondingly, dense rock types increased the gravity field and causes local gravity high.

Changes in a gravity field along the measurement profile provide information about the effective density contrast between materials. A sharp change in the gravity field is always caused nearby source. Overburden thickness variation is one such factor. A slender change in gravity field is caused by a distant density variation, OR alternatively a gradual change in nearby density. This kind of ambiguity in the gravity interpretation is impossible to solve without additional information. The uncertainty of gravity interpretation can be reduced, for example, by including geological facts and measuring the densities of local rock samples. There are plenty of other possibilities to reduce ambiguity of the gravity data interpretation. However, this report focuses only on data acquisition.

Different location and time related effects in gravity field are removed from the measured gravity data to highlight geological density variations. After data processing the results are typically presented as a Bouguer anomaly maps or profiles. The process applies standard calculations to uniform and combine new and old gravity results together in local and global scale. The process is explained more detailed further in this report.

## 4.1 Existing gravity data and survey plan

The previous regional gravity data was measured by Finnish Geospatial Research Institute (FGI), previously known as The Finnish Geodetic Institute. FGI is a research and expert unit of the National Land Survey of Finland (NLS). Bouguer anomaly values of initially unevenly distributed measuring stations was interpolated to 2,5 km x 2,5 km grid related to the preparation of the Fennoscandian Bouguer anomaly map (Korhonen et al. 2002). The published map consists of ISGN 71 Bouguer anomaly values in WGS84 coordinate system and Gauss-Krueger projection with central meridian of 21°E, false easting 1 500 000. Terrain correction was calculated and finally the anomaly field was continued upwards to 500 m above the ground level. Bouguer anomaly map of the Kuusamo study area made from the Finnish part of this Fennoscandian Bouguer anomaly grid, is presented in Figure 1. The map is shaded according to the magnitude of the horizontal gradient of the Bouguer anomaly.

The plan of new regional gravity survey covers about 20 km wide and 60 km long zone north of Kuusamo and NE of Posio. The survey area is delineated by a blue polygon on

the map in Figure 2. East and North coordinates of the polygon corners are collected in Table 2.

*Table 2. Corner coordinates of the survey area polygon. Coordinates are presented in EUREF-TM35FIN coordinate system.*

| Corner | East | North | Corner | East | North |
|---|---|---|---|---|---|
| 1 | 567609 | 7372076 | 9 | 609810 | 7327838 |
| 2 | 569726 | 7371746 | 10 | 592216 | 7319226 |
| 3 | 572504 | 7370158 | 11 | 560321 | 7357227 |
| 4 | 576418 | 7369880 | 12 | 558922 | 7358591 |
| 5 | 577850 | 7368550 | 13 | 560798 | 7361763 |
| 6 | 596540 | 7345836 | 14 | 561987 | 7364271 |
| 7 | 606106 | 7333857 | 15 | 561855 | 7369100 |
| 8 | 611464 | 7331013 | | | |

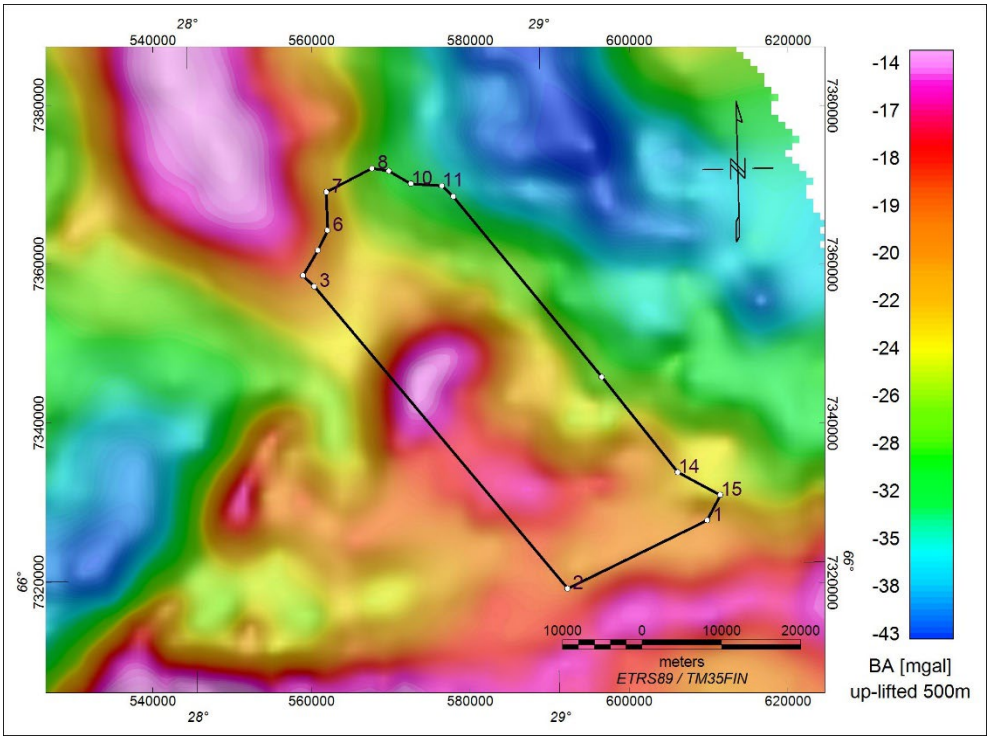


*Figure 2. Previously measured regional Bouguer anomaly map with borders of new survey area (black polygon). Shading represents horizontal gradient of Bouguer anomaly. Presented gravity data is provided by FGI (Finnish Geospatial Research Institute).*

Traditionally, in such regional gravity projects, measuring stations are located at an even distance from each other. Some stations are easily accessible near roads, but not all. Moving from the station to the next station takes up most of the working time. Field assistants must navigate to stations, carry a gravimeter and positioning device, and move sometimes in difficult conditions. To improve measurement efficiency, this project was designed to be carried out along roads. The main plan consists of 2562 stations. In addition, 586 stations were planned for snowmobile trails and the ice of the lakes. The total number of planned gravity stations was 3148.

The gravity stations were planned at easily accessible locations in the vicinity of roads and snowmobile trails. Each measuring station could also be moved to a new nearby location depending on local conditions and working safety. New technology such as precise GNSS positioning systems and digital elevation models have enabled such operations.

The locations of the measurement stations were generated using the ArcMap program. For all different roads, a measuring site was calculated every 500 meters. Subsequently, the locations of all stations were checked and, if necessary, corrected. For ice areas, measurement sites were placed in a 500m x 500m grid.

Basically, each gravity measurement provides additional information and helps study regional geology. However, unevenly distributed measurement data can cause quality problems. One problem involves the interpolation of profiles and maps. Covering blank spaces between stations can be interpolated in many ways with different results. The uncertainty of interpolated values can be assessed by different calculation methods, but the outcome is never equivalent to the actual gravity measurement done at the site. The other problem is associated to regional geology. Roads may have been built in a certain type of suitable surroundings and, on the other hand, those areas where roads are not built have some geological feature. The location of the observations is not evenly distributed in terms of soil thickness, for example, and there is often a difference in height between a ditch and a road near the measurement station.

## 4.2 Gravity data Acquisition

Regional gravity measurements were carried out between 16 Nov 2021 and 25 Oct 2022. License to operate in the vicinity of the public roads was granted by ELY (Centre for Economic Development, Transport and the Environment) in 16 Nov 2021. License was valid from 1 Dec 2021 to 30 Sep 2022. Press release was published on 16 Nov 2021 to inform local people.

### 4.2.1 Instrumentation

The gravity survey was conducted with relative gravimeters which are easily transportable instruments for such a scientific project. Typical gravimeter Scintrex CG-5

is shown in Figure 3. The gravimeter is set and carefully levelled on a stand for taking an accurate reading. During several minutes the instrument records a series of readings of the deformation of a quartz spring. Relative instruments do not measure the absolute value of free fall acceleration (gravity), but the relative value between some measurement limits. The relative readings are converted to gravity values using calibration constants specified separately for each gravimeter.


*Figure 3. Gravimeter Scintrex CG-5.*

Calibration of gravimeters was performed on 7 June 2022 on the Otaniemi-Masala-Vihti calibration line. Calibration line consists of seven measuring stations along the 50 km long route. The first part of the measurement from Otaniemi to Vihti was made during the morning. The second part of the measurement, a repeat measurement in the reverse order, was made in the afternoon. The measurement route is well suited for calibration; there is enough variation in gravity values and the work cycle lasts long enough. In practice, it has been noted that a round trip over a single day via multiple intermediate stops is an effective way to perform a calibration measurement. Information of calibration stations are presented in Table 3. Gravimeters and calibration constants are presented in Table 4.

*Table 3. Stations of Otaniemi-Masala-Vihti calibration line. Gravity values (g[mGal]) in Masala and Vihti are fixed according to the most recently measured absolute values by FGI.*

| ID | East | North | g [mGal] | Location |
|---|---|---|---|---|
| **220001** | 379605 | 6673666 | | Otaniemi |
| **971007** | 363810 | 6671845 | 981909.2742 | Masala |
| **971008** | 359107 | 6682264 | | Haapajärvi |
| **971009** | 356631 | 6686633 | | Veikkola |
| **971010** | 352825 | 6690293 | | Nummela |
| **971011** | 353116 | 6697859 | | Raja-ahde |
| **971012** | 353532 | 6703252 | 981962.1813 | Vihti |

*Table 4. Calibrated gravimeters.*

| Gravimeter | Serial Number | Constant | St.dev |
|---|---|---|---|
| **Scintrex CG-5** | 40306 | **0.9998747** | **0.0001160** |
| **Scintrex CG-5** | 7 | 0.9993354 | 0.0001099 |
| **Scintrex CG-6** | 21080371 | 1.000015 | 0.000026 |

GTK has more gravimeters than calibrated in summer 2022. The other gravimeters have older calibration constants saved inside the gravimeters. Gravimeters used in the Kuusamo survey are presented in Table 5.

*Table 5. Used gravimeters in Kuusamo regional gravity survey.*

| Gravimeter | Serial Number | Constant | St.dev |
|---|---|---|---|
| **Scintrex CG-5** | 1804008 | | |
| **Scintrex CG-5** | 40702 | | |
| **Scintrex CG-5** | 7 | 0.9993354 | 0.0001099 |

The positioning of gravity stations was measured with handheld GNSS (Global Navigation Satellite System) method. New Trimble R12i instruments were purchased in early 2022 for GTK. Before this the used system was Javad Triumph 1-M VRS-GPS. The

new positioning system has 1 cm accuracy due to Virtual Reference Station (VRS) correction. The correction uses Geotrim Oy's Real Time Kinematic (RTK) solution with 4G network connection.

### 4.2.2 Field work

The fieldwork was carried out by several working groups. The group typically consists of two research assistants. Sometimes both groups worked simultaneously at the Kuusamo region. Typically, Monday and Friday were travel days. Occasionally, the work period extended over the weekend. The numbers of stations measured in different months are visualized on blue pillars in Figure 4. The cumulative number of all measuring stations (2378 stations) is shown by the orange line.

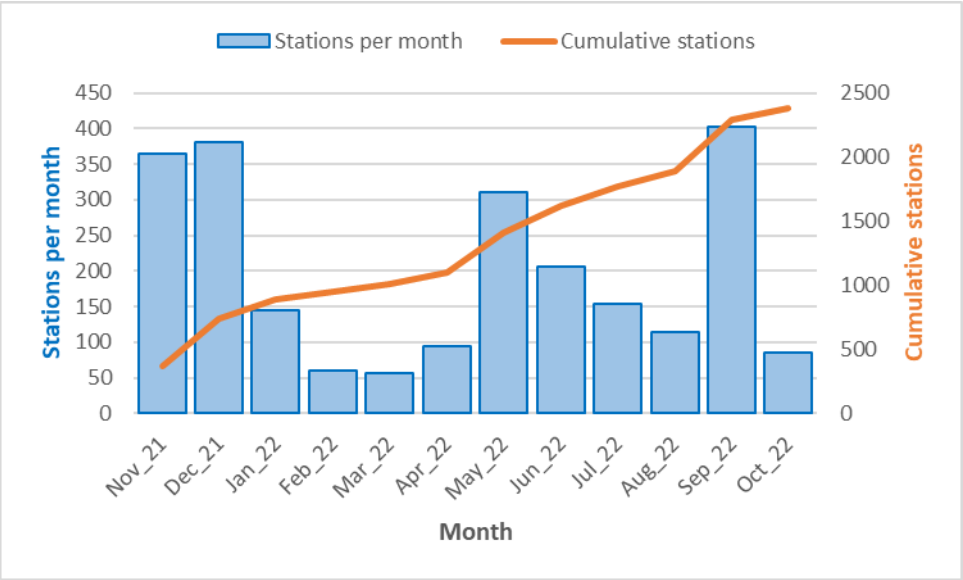


*Figure 4. Progress of measurements.*

The measurement proceeded well when journeys were made by cars. About 90% of road stations were measured. It was impossible to reach all planned stations due to locked roads or other similar reasons. Work slowed significantly when moving along snowmobile trails. Poor ice conditions prevented measurement on the lake's ice. Only about 20% of the additional measurements were measured.

During fieldwork, one research assistant collected rock samples from near measured gravity stations. Most rock samples (n = 20) have exact coordinates, but some (n = 4) coordinates need to be checked later. The rocks samples are planned to be analyzed at GTK's petrophysical laboratory in Espoo. The results are a useful addition to previous data collected from the Kuusamo region.

### 4.3 Gravity data processing

Data processing takes place in two stages. The first stage is carried out daily after measurements. The second step is done finally, after all measurements have been completed.

The measured gravity values are tied to the FOGN (First Order Gravity Net) provided by FGI. FOGN station number 620028 in Kuusamo was used as the base for the survey. Coordinates are in ETRS-TM35FIN system East 599350.72 and North 7317430.50, in WGS84 system East 29°11’10’’ and North 65°57’44’’, and elevation in N2000 systems h 259.28m. Updated gravity value on the station is 982 272.39 mGal.

#### 4.3.1 Preprocessing

The field team submits the measured data daily to a MAMI (Finnish for Maastomittaukset, eng. Field Measurement) system. The system is a unique GTK inhouse build software developed for a centralized data handling and quality control supervision. The system initially checks certain specified header and parameter information from the data. The system also compares the input data to known DEM (digital elevation model), the difference between planned/measured location and informs the user if any deviation, from set boundary limits, are exceeded.

Each project that cumulates basic field measurement data in GTK has a named person responsible for the preprocessing and quality control of the data. The person, most often a geophysicist, is a part of a named processing team and checks the delivered data daily. The close go-operation with the field team and timely mannered data surveillance is the main method for reliable and good quality data.

The preprocessing includes processing of the data with a GTK inhouse software, Ravitaattori. The software combines the elevation information (in .txt or .prt file format) and the gr information (in .gr format and converted to .CG-5 or .CG-6 format, same information just different format) to one file (.xyz format). For the xyz-file the software calculates the normal gravity to the observation height (to the top of a measurement stand) and the bouguer value to the surface of the earth.

The Normal gravity value (g0) of each gravity station measured is calculated by the formula defined in the Geodetic Reference System 1980 (GRS1980). The latitude φ is in Finland according to the EUREF-FIN datum (WGS84 system).

$g_0(1980)$ /mGal = 978 032.67715 * (1 + 0.005 279 0414 * $\sin^2\varphi$ + 0.000 023 2718 * $\sin^4\varphi$ + 0.000 000 1262 * $\sin^6\varphi$ + 0.000 000 0007 * $\sin^8\varphi$)

The Bouguer values by Ravitaattori are calculated by:

$\Delta gB = gM(FOGN) - g0(1980,EUREF\text{-}FIN) + \delta gatm - \delta gh(N2000) - 0.1119 * h(N2000)$

| | | |
|---|---|---|
| Where | $\Delta g_B$ = | Bouguer anomaly /mGal |
| | $g_M$ = | measured gravity /mGal |
| | $g_0$ = | normal gravity /mGal |
| | h = | height above sea level /m |
| | $\delta g_{atm}$ = | atmospheric correction / mGal |
| | $\delta g_h$ = | 2nd order free-air gradient/GRS80 /mGal |

The constant 0.1119 implies that the Bouguer density is 2670 kg/m$^3$.

The software also writes collective processing notes for all the base station information and for the calculated drift. The software is also used to calculate the base station values for each new base station of the survey area, initially tied to the FOGN.

**<u>GR-format includes</u>**

/ gtk 50404-4021022 T513, T514, S524, S542 **project information and map sheets**
/ LIUSKEJAKSO KUUSAMO APV ja Kuusamon liuskejakson APV lisätilaus **project information**
/ 16.11.2021 - 25.10.2022 AI PK JK JI PM **Date and initials of measurers**
/ Gravimetrinen mittaus CG-5 Autograv no: 1804008 40702 7 **equipment information**
/
/ 7316580 559404 7373051 610782 **min and max coordinates of the area**
/
/
/ Runkoarvoasema 620028 2272.39 **Used FOGN base station**
/ X Y Matka Z_maa Boug g_abs Z_hav jalusta lumi vesi Piste_nmr Linja_nmr mittaustapa PVM **Header information**
/ Matka laskettu linjalle projisoituna ja painovoiman absoluuttiarvo jalustan päälle **Information on the calculations**
/
Line 0
/ X Y Matka Z_maa Boug g_abs Z_hav jalusta lumi vesi Piste_nmr Linja_nmr mittaustapa PVM
610528.449 7316579.944 0.00 270.064 -30.147 982269.942 270.714 0.650 0.000 0.000 2261156 0 gps 05.07.2022

The data, when in .zyz format, is then checked in Oasis Montaj software by plotting each measurement point / line. Any abnormalities in the measured values are checked, the heights are compared to existing lidar information and if possible corrected at the processing table. If the data does not fullfill the set quality standards it is measured again.

For example for this project some height measurements (10 points) were measured again with the new GPS device as the initial measurements did not fullfill the quality standards.

### 4.3.2 Final processing

After preprocessing Geosoft Oasis Montaj software was used for final data processing. The different steps of processing are described below:

Averaging absolute gravity values of each repeat measurement point and evaluating quality of individual measurements. Some poor-quality measurements were removed.

During the winter measurement, the thickness of snow cover was also measured. Snow correction, which is included in the absolute gravity values, was calculated using snow density 300 kg/m$^3$.

Using air gradient value of 0.3084 mgal/m, absolute gravity values were reduced from the measurement height to the ground level.

Digital elevation model (10mx10m) of National Land Survey of Finland was used for terrain correction within distance of 18.8 km from each gravity station. Terrain density 2670 kg/m3 was used.

The latitude values of KKJ and ETRS89 datums needed for the calculation of Bouguer anomalies were calculated in the web service of National Land Service and imported to Oasis Montaj.

Two different gravity formulas were used for Bouguer anomaly calculations. International Gravity Formula 1930 (IGF 1930) with coordinate datum KKJ and height datum HN60 was used as an older system. Geodetic Reference System 1980 (GRS80) was used with coordinate datum ETRS89 and height system HN2000 as a newer system. Formulas for free-air and Bouguer anomalies are represented below:

International Gravity Formula 1930 (OLDER SYSTEM):

$\Delta g_F = g_M(FOGN) - (g_0(1930,KKJ) - 14.00) + 0.3084 * h(N60)$

$\Delta g_B = g_M(FOGN) - (g_0(1930,KKJ) - 14.00) + 0.3084 * h(N60) - 0.1119 * h(N60) + (TK)$

Geodetic Reference System 80 (GRS80, NEWER SYSTEM):

$\Delta g_F = g_M(FOGN) - g_0(1980,ETRS89) + \delta g_{atm} - \delta g_h(GRS80) * h(N2000)$

$\Delta g_B = g_M(FOGN) - g_0(1980,ETRS89) + \delta g_{atm} - \delta g_h(GRS80) * h(N2000) -$
$- 0.1119 * h(N2000) + (TK)$

where $g_0\,(1930,KKJ) = 978049 * (1 + 0.0052884 * \sin^2\varphi - 0.0000059 * \sin^2 2\varphi)$

$$g_0\,(1980,ETRS89) = 978032.67715 * (1 + 0.005\,279\,0414 * \sin^2\varphi + 0.000\,023\,2718 * \sin^4\varphi + 0.000\,000\,1262 * \sin^6\varphi + 0.000\,000\,0007 * \sin^8\varphi)$$

$$\delta g_{atm} = 0.874 - 9.9 * 10^{-5} * h(N2000) + 3.56 * 10^{-9} * h(N2000)^2$$

$$\delta g_h = -(0.3087691 - 0.0004398 * \sin^2\varphi) * h(N2000) + 7.2125 * 10^{-8} * h(N2000)^2$$

| | |
|---|---|
| $\Delta g_F$ | = free-air anomaly /mGal |
| $\Delta g_B$ | = Bouguer anomaly /mGal |
| $g_M$ | = measured gravity /mGal |
| $\varphi$ | = latitude (in KKJ or ETRS89 system) |
| $g_0$ | = normal gravity /mGal |
| h | = height above sea level /m |
| TK | = terrain correction /mGal |
| $\delta g_{atm}$ | = atmospheric correction / mGal |
| $\Delta g_h$ | = free air gradient |

The constant 0.1119 implies that the Bouguer density is 2670 kg/m$^3$.

The final data contains 2378 gravity station. Data is stored in GTK's Regional Gravity Data format the content of which is described in the following list:

Regional Gravity Data Description:

| | Column | Description |
|---|---|---|
| 1. | KL_KKJ | KKJ Map Sheet |
| 2. | NRO | Station Identification |
| 3. | X_KKJ | Northing /m /KKJ |
| 4. | Y_KKJ | Easting /m /KKJ |
| 5. | H_N60 | Height /m /N60 |
| 6. | G_FOGN | Gravity according to FOGN system /mGal |
| 7. | GB | Bouguer anomaly /mGal /International Gravity Formula 1930 |
| 8. | GBTK | Terrain corrected GB /mGal |
| 9. | GVH | Estimated Relative Mean Error |

Gravity (G), Vertical (V), Horizontal (H)

| G | V H |
|---|---|
| 0 <0.010 mGal | 0 0 <0.01 m |
| 1 <0.040 mGal | 1 1 <0.05 m |
| 2 <0.100 mGal | 2 2 <0.10 m |
| 3 <0.200 mGal | 3 3 <0.50 m |
| 4 <0.300 mGal | 4 4 <1.00 m |
| 5 <0.500 mGal | 5 5 <2.00 m |
| 6 <1.000 mGal | 6 6 <5.00 m |
| 7 <2.000 mGal | 7 7 <10.0 m |

| | | | |
|---|---|---|---|
| | | 8 <5.000 mGal | 8 8 <20.0 m |
| | | 9 <10.00 mGal | 9 9 <100. m |
| 10. | PVM | Date DDMMYYY | |
| 11. | TK | Terrain Correction /mGal /Radius 18.8 km | |
| 12. | JS | Water Depth /m | |
| 13. | LS | Snow Cover /m | |
| 14. | IMO | Data Source (Institute, Company) | |
| | | 0 = Geological Survey of Finland | |
| | | 1 = Finnish Geodetic Institute | |
| | | 2 = Suomen Malmi Oy | |
| | | 3 = Outokumpu Mining Oy | |
| | | 4 = Astrock Oy | |
| | | 5 = University of Oulu | |
| | | 6 = Helsinki University of Technology | |
| | | 7 = Rautaruukki Oy | |
| | | … | |
| 15. | ISEC | Security | |
| | | 0 = Public | |
| | | 1 = In-house | |
| | | 3 = Proprietary | |
| | | … | |
| 16. | XUTM | Northing /m /UTM /EUREF-FIN | |
| 17. | YUTM | Easting /m /UTM /EUREF-FIN | |
| 18. | H_N2000 | Height /m /N2000 | |
| 19. | GB80 | Bouguer Anomaly /mGal /GRS80-system | |
| 20. | GB80TK | Terrain Corrected GB80 /mGal | |
| 21. | KL_EUREF | UTM Map Sheet | |

## 4.4 Quality

The data quality is generally good. The estimated relative mean error for gravity measurement made on the ground is below 0.1 mGal. For the measurements made on the ice of lakes (38 stations), the vibration of the ice mainly caused by the wind caused a bigger error estimate of <0.3 mGal at its worst.
Although there are holes in the data on lakes and roadless areas, the first impression of the data is positive. There is a nice variation in the Bouguer anomaly in the area matching well with the known geology. Terrain corrected Bouguer anomaly (GB80TK) varies about 20 mGal, from -27 to -47 mGal with the average being -36.817 mGal.

## 4.5 Results

The result of the gravity survey is the regional Bouguer anomaly variation. The variation in the Bouguer anomaly reflects geologic density variation. Effects such as the height of

the measurement station and surrounding topographic variation have been removed from the initial measurement result.

The realized gravity stations on the Bouguer anomaly map are shown in Figure 5. The map is interpolated using the minimum-curvature gridding method. The blanking distance used has been 1500 meters and therefore larger areas without gravity data appear empty.

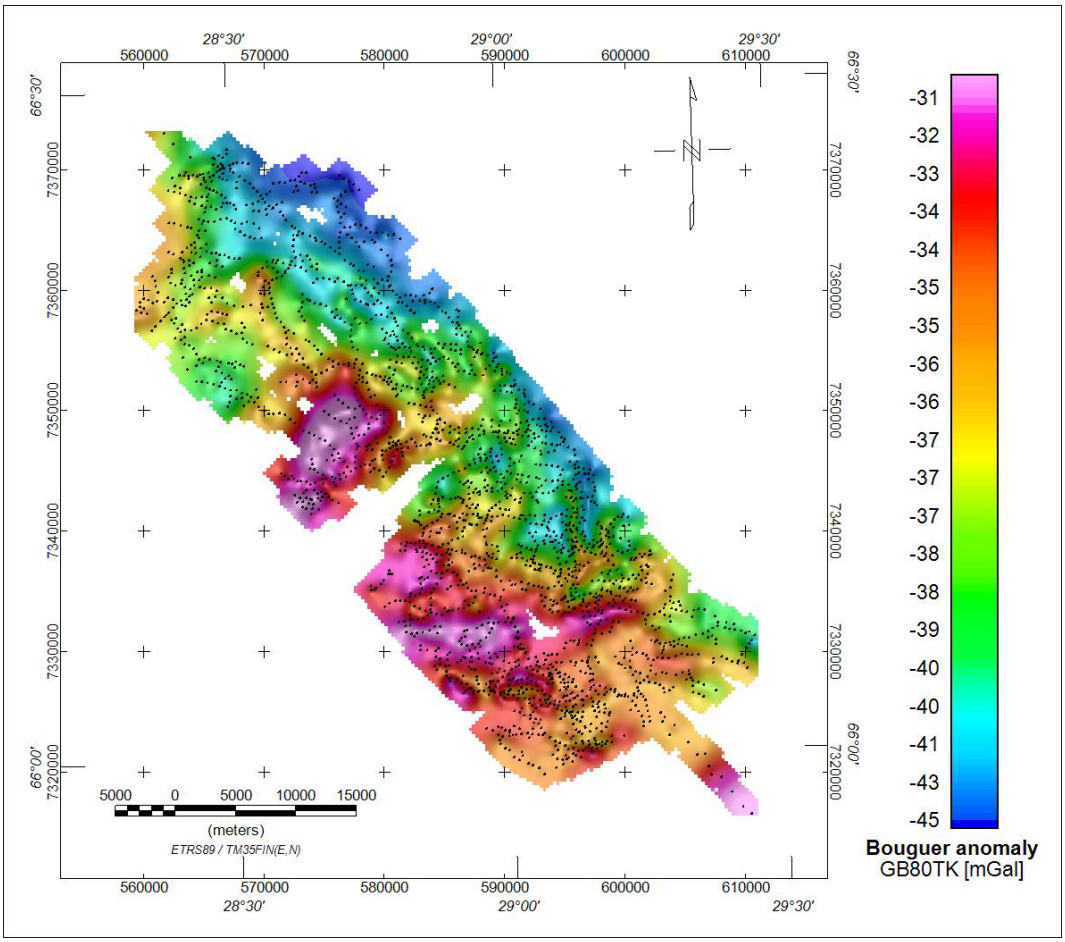


*Figure 5. Measured Bouguer anomaly variation. Red color indicates dense rocks and blue lighter rocks. Shadows describe the intensity of the horizontal gradient. Locations of measured gravity stations (n=2378) are marked with black dots.*

The density of the gravity stations is visualized in Figure 6. Most of the region has been measured at the density of 3 to 5 stations per square kilometer. However, due to gaps, the average density is about 2 stations per square kilometer.

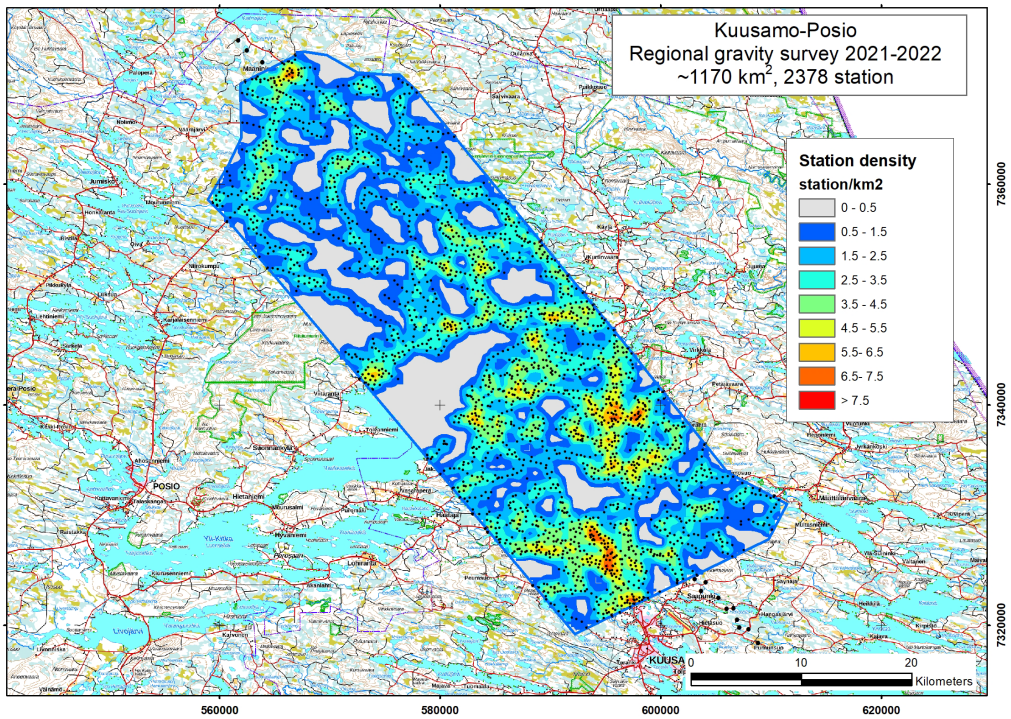


*Figure 6. The station density of gravity survey. The background map provided by the National Land Survey of Finland, 2022.*

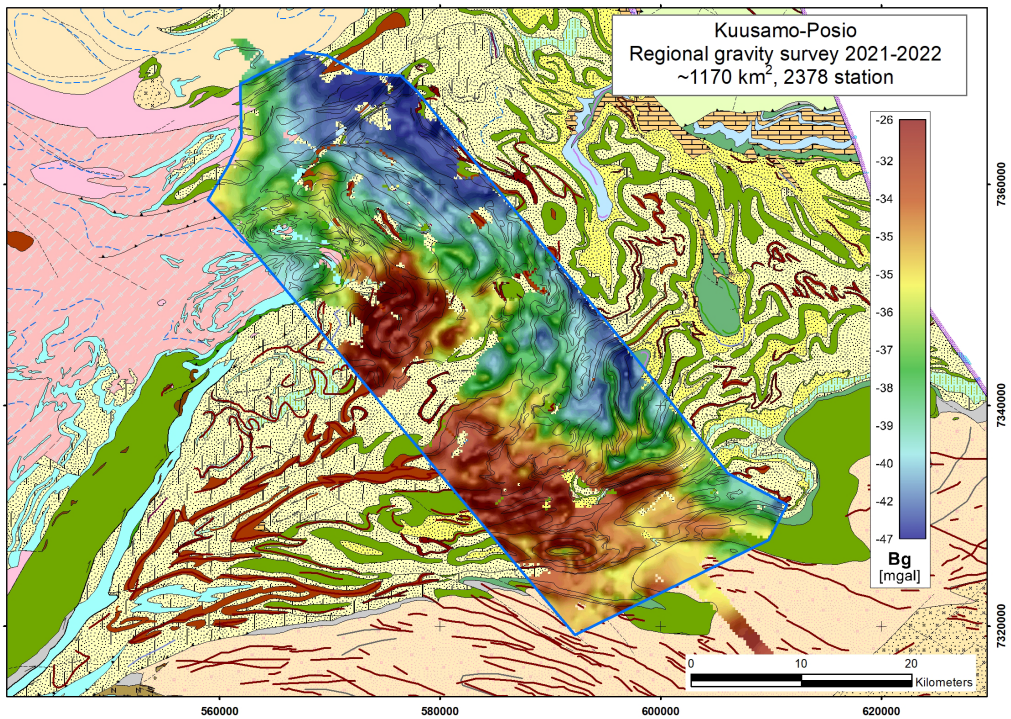


*Figure 7. Bouguer anomaly on bedrock map.*

No interpretation has yet been made for the measurement results. However, the Bouguer map can already be compared to a geological map. Several small and sharp anomalies have good compatibility with distribution of different lithological units (Figure 7). Two larger anomaly peaks stand out in the area. Since there is no gravity data from the NE part of the Yli-Kitka Lake, i.e., between the anomalies, it is uncertain what kind of gravity there is between the maxima.

Although there are several gaps in the data, Bouguer anomaly data provides a much more detailed picture of geology than before. For comparison, a Bouguer anomaly map continued 500 meters upward is shown in Figure 8.

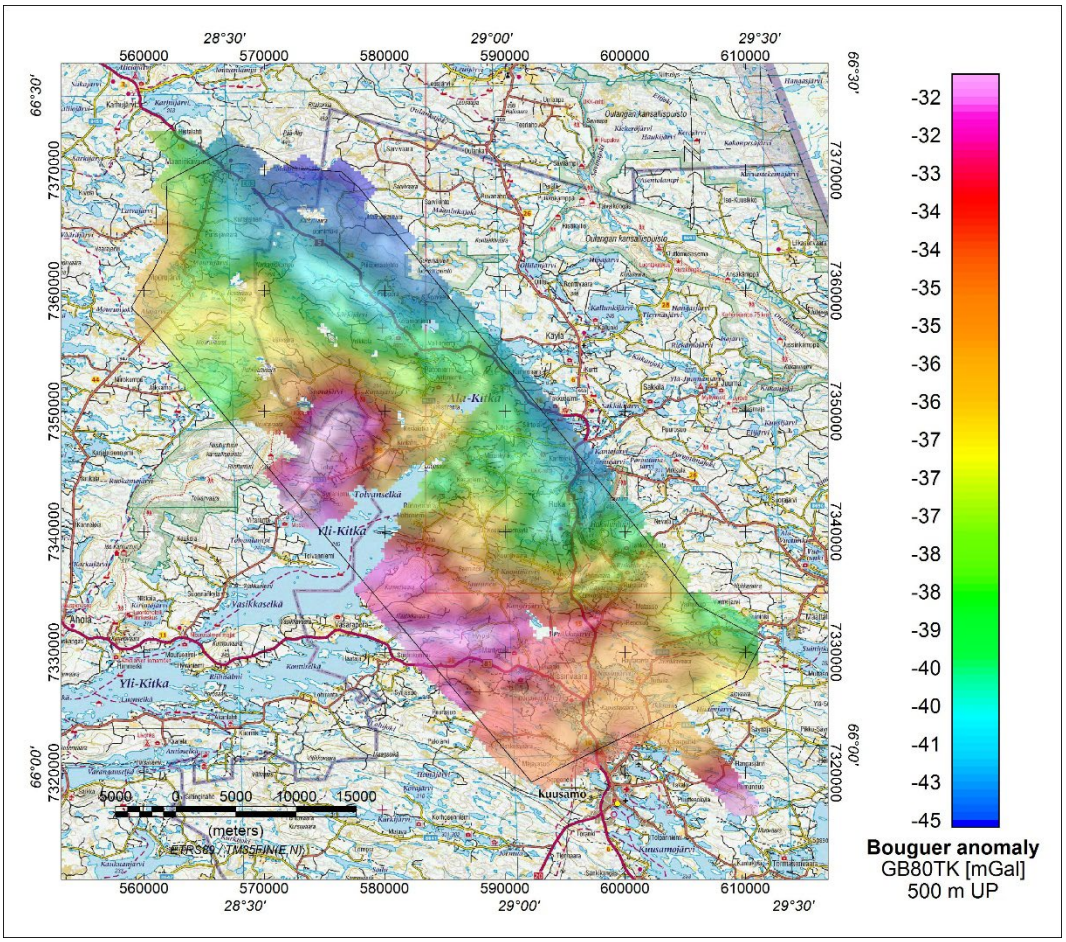


*Figure 8. Bouguer anomaly map, continued upward 500 meters. Shadows indicate magnitude of horizontal gradient. The background map provided by the National Land Survey of Finland.*

## 5 DATA ARCHIVING

The acquired MT data set contains approximately 250 GB of raw electric and magnetic time series data. The raw data are stored in binary format (.ats) as produced during the data recording. The transfer functions processed from the raw data are stored in the standard EDI-format. The archived transfer functions are oriented in the geographic coordinate system i.e., the transfer functions were rotated from the original geomagnetic coordinate system by the amount defined by the declination in the measurement area. During the measurements declination was 14 degrees towards east. All raw and processed data described in this report are stored in GTK databases.

Gravity data set will be stored in GTK databases. The material will not be released immediately, but only after the BATCircle2.0 project ends.

## 6 CONCLUSION

The MT data acquisition commenced in February 2022 with a lake-ice experiment. The main portion (non-lake sites) of the MT data were acquired during May–September. MT data from total of 152 sites were acquired during 2022. The data set contains 2-, 4- and 5-channel recordings. Processing of raw time series data produced high quality transfer functions in the period range of 0.005–256 s for later modelling work.
The regional gravity survey of the Kuusamo region was successfully carried out. During the year, gravity was measured at 2378 measuring stations. Gravity stations designed for ice in the lakes could not be implemented except to a small extent due to the poor ice conditions. The conducted survey provides a gravity data set for gravity modeling and geological interpretation. However, we recommend continuing the measurement to fill in the gaps.

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